PHYSIOLOGY & OPERATIONAL ISSUES IN HOT WEATHER

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MEDICAL IMPACT OF HEAT STRESS

Military

- During Word War II, U.S. forces suffered >35,000 heat injuries requiring hospitalization.
- 20,000 Egyptians died from heat injuries during the Six-Day 1967 War with Israel
- In Grenada, 2.9 - 4.8% /day suffered heat injuries & were treated at Battalion Aid Stations.

Civilian

- 465 deaths from heat injuries in Chicago over 7 days in 1995.

Outline

- Heat Stress & Strain
- Physiology & Tolerance
- Heat Stress Management
  - Heat Acclimation
  - Hydration & Fluid Replacement
  - Exercise - Rest
  - Microclimate Cooling
- Hot Weather Guidelines

Heat Stress & Strain

HEAT STRESS / STRAIN FACTORS

CLIMATE x MISSION x BIOMEDICAL

- Temperature
- Humidity
- Wind
- Altitude

- Metabolic Rate
- Duration
- Type of Work
- Clothing / Equipment

- Age
- Anthropometry
- Gender
- Health
- Sleep Status
- Acclimation
- Aerobic Fitness
- Emotions - Motivation
- Hydration
- Pharmaceuticals

Heat Stress / Strain Assessment

- **Environmental Heat Stress**
  - **Wet Bulb Globe Temperature (WBGT)**
- **Environmental / Task Integration**
  - **USARIEM Heat Strain Models**
  - **Effective Temperature (ET*)**
- **Physiologic Strain**
  - **Predicted 4-h Sweat Rate (P4SR)**
  - **Physiological Strain Index (PSI)**

WET BULB GLOBE TEMPERATURE (WBGT)

Outdoors :
WBGT = 0.7 Wet Bulb + 0.2 Black Globe + 0.1 Dry Bulb

Indoors:
WBGT = 0.7 Wet Bulb + 0.3 Black Globe

Yaglou &. MInard, AMA Arch. Ind. Health, 1957

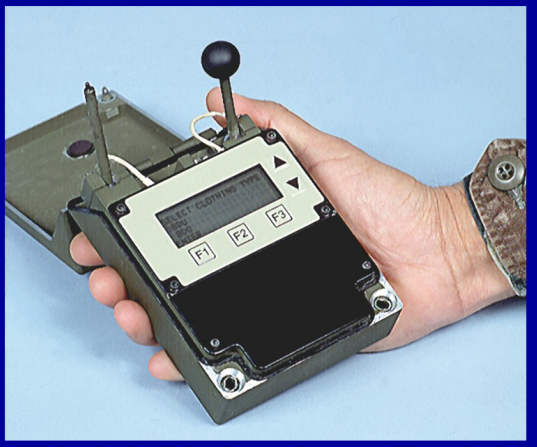
WET BULB GLOBE TEMPERATURE (WBGT)

- Developed for Resting Comfort & Marching
- Does Not Account for Metabolic Rate
- Underestimates Risk in Humid Conditions
- Assesses Risk of Heat Injury
- Dictates Level of Medical Surveillance

Heat Stress Monitor (HSM) Concept

User Selects from Display Menu:

- Clothing type
- Work Rate
- Acclimation status



HSM Automatically Measures:

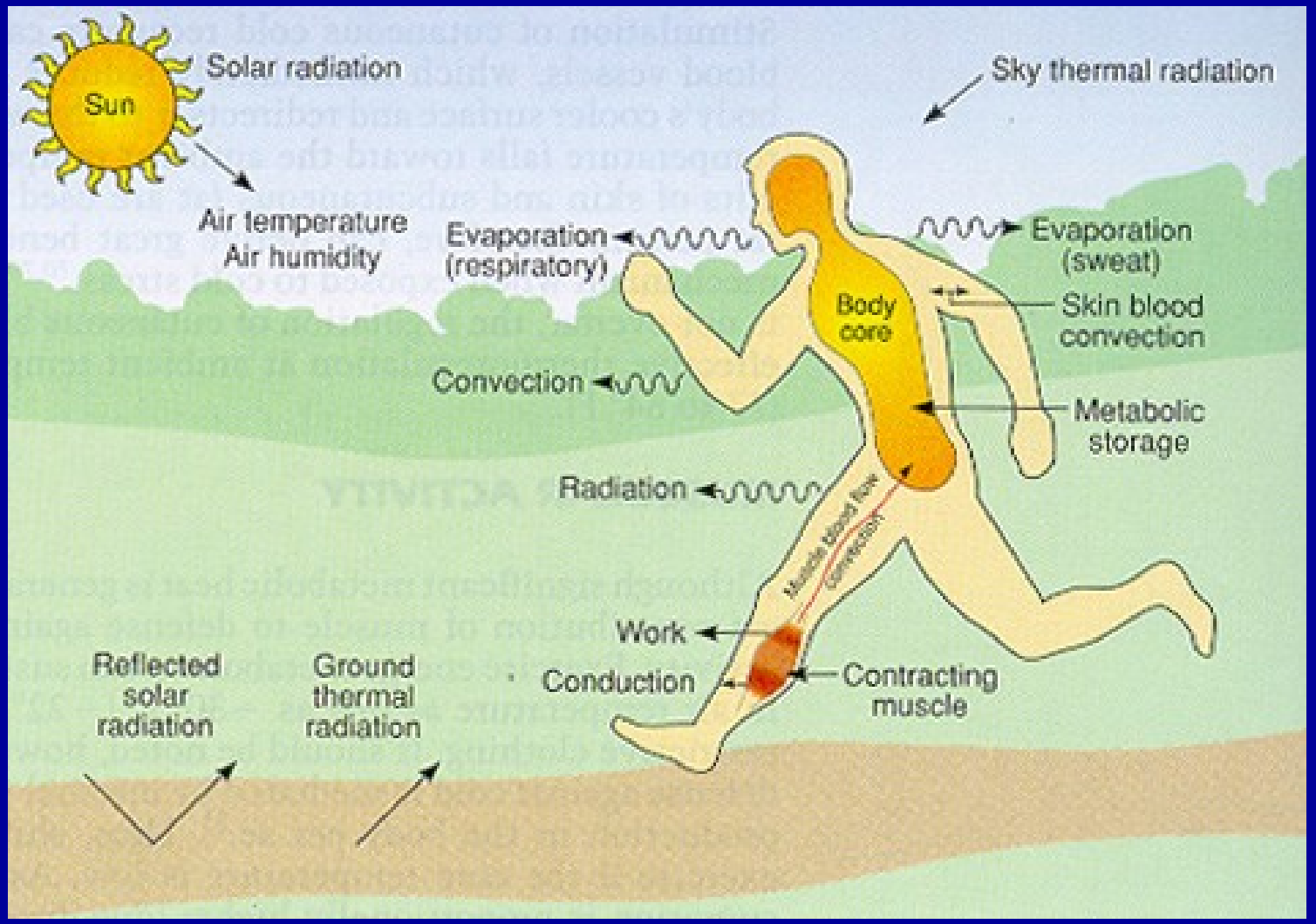
- Air temperature
- Humidity
- Solar Radiation
- Wind speed

HSM Automatically Computes and Displays:

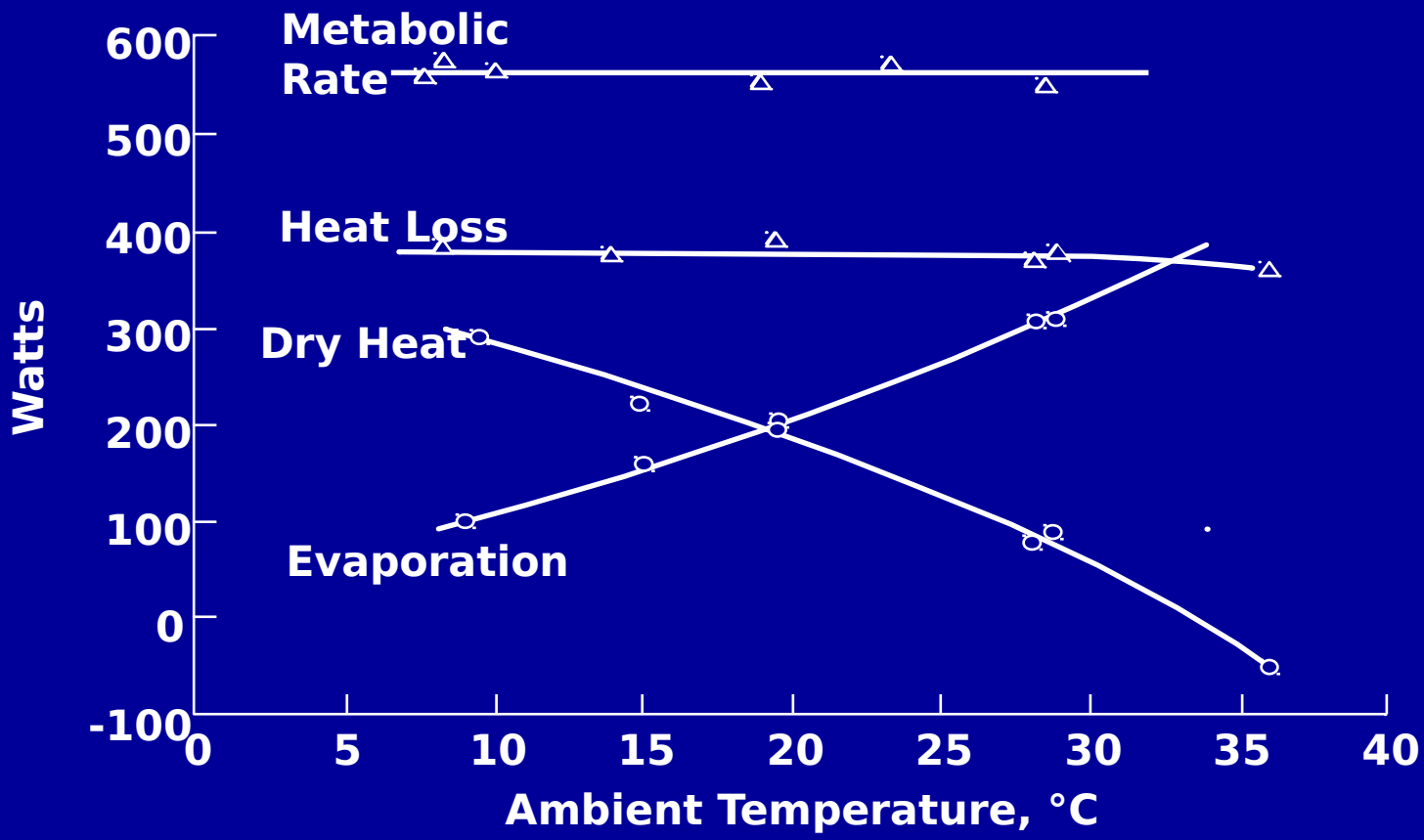
- Optimal Exercise / Rest Cycle Limits
- Hourly Water Consumption
- Maximum Safe Work Time
- Other measured and computed variables

Physiology & Tolerance

Physiology of Heat Stress

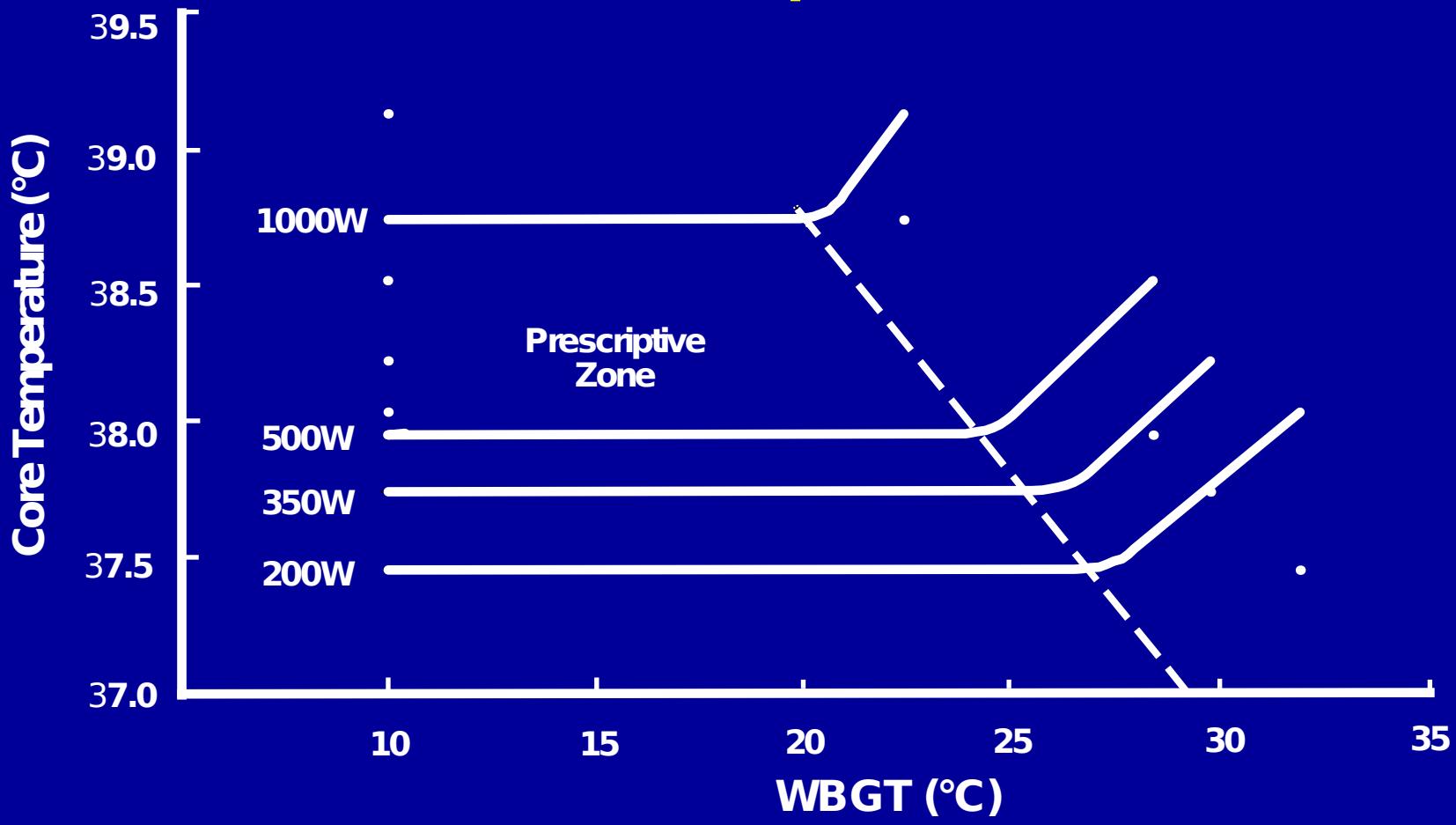


Avenues of Heat Exchange at Different Ambient Temperatures



Nielsen Skand Arch Physiol 79: 193,1938.

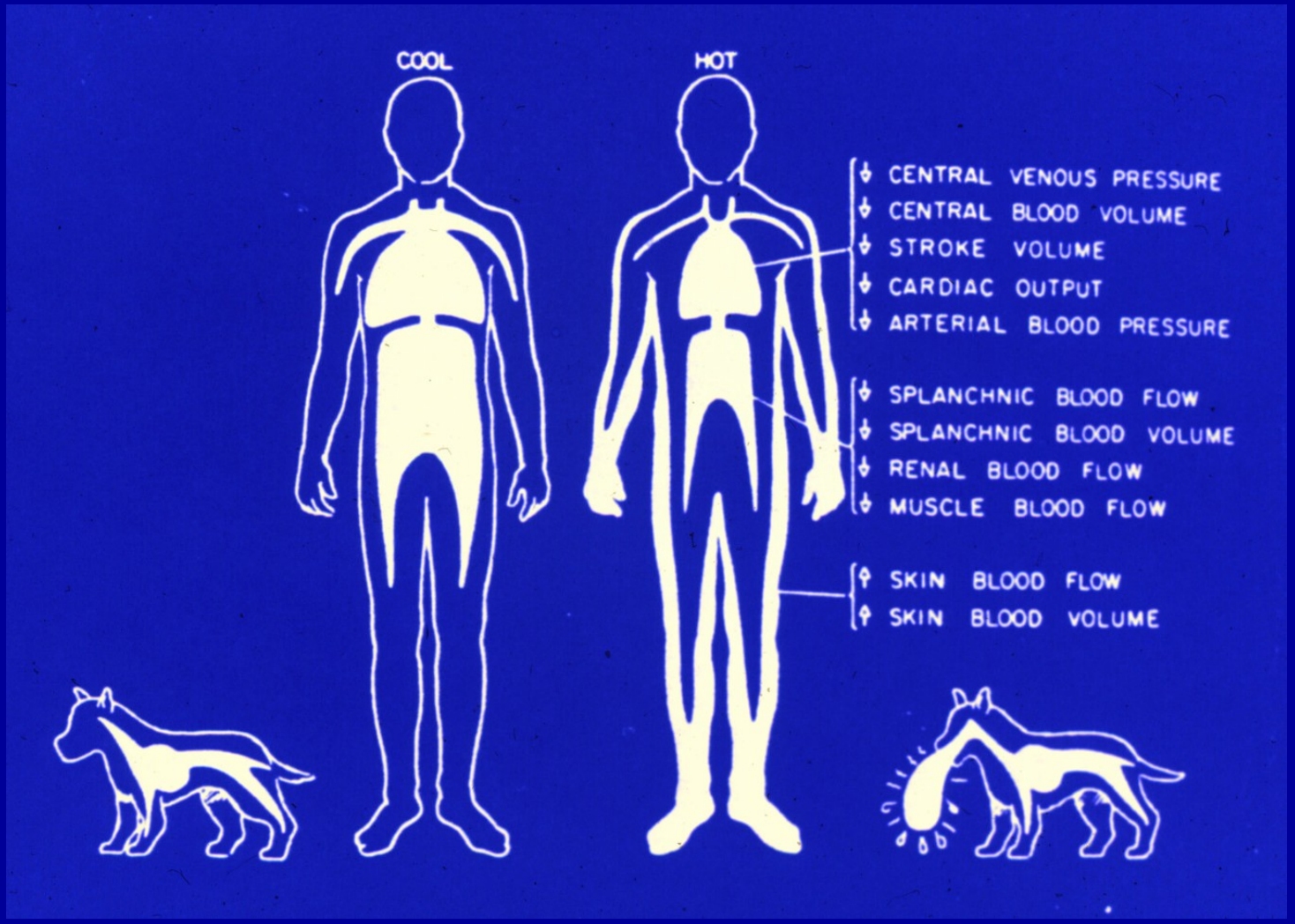
Work Rate & Climate & Effects on Core Temperature



Heat Stress

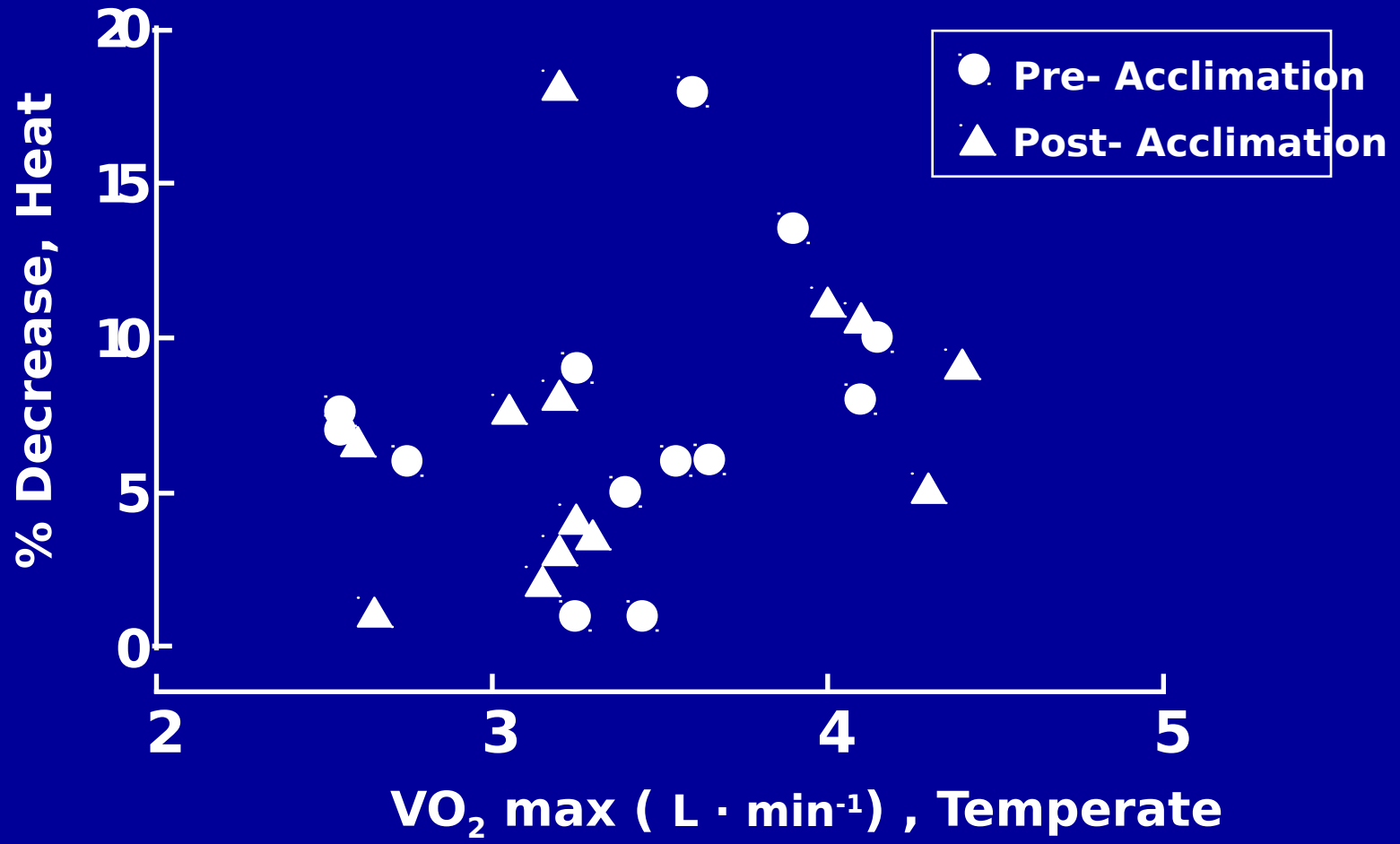
- **Compensable: Biophysics allow adequate sweat evaporation to maintain steady - state core temperature.**
  - **Controls: Heat Acclimation, Rehydration**
- **Uncompensable: Biophysics limit evaporative cooling below required levels.**
  - **Controls: Exercise / Rest Ratios, Microclimate Cooling**

Heat Stress Displaces Blood from Core to Periphery



Rowell Human Circulation 1986

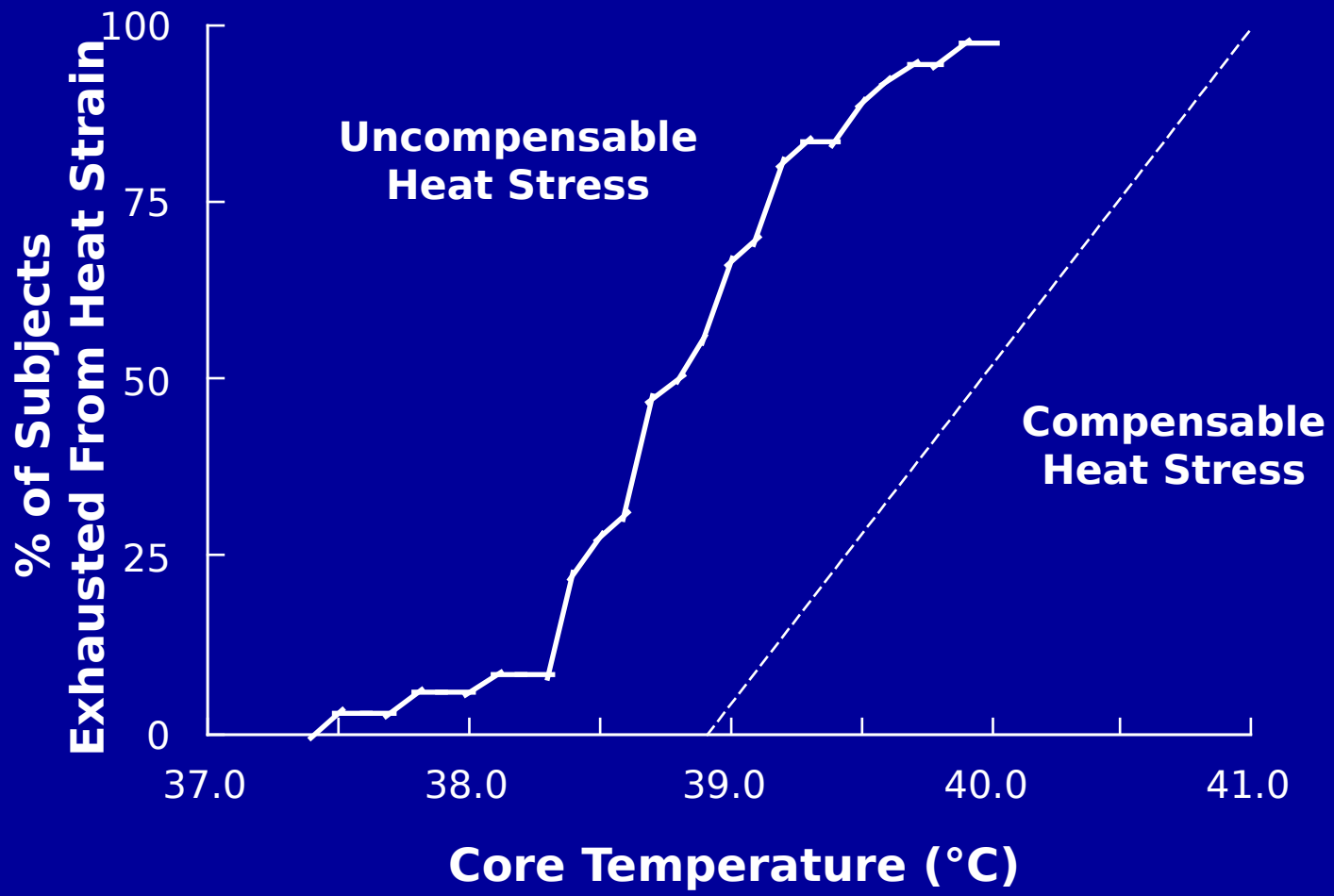
HEAT STRESS DECREASES VO_2 max

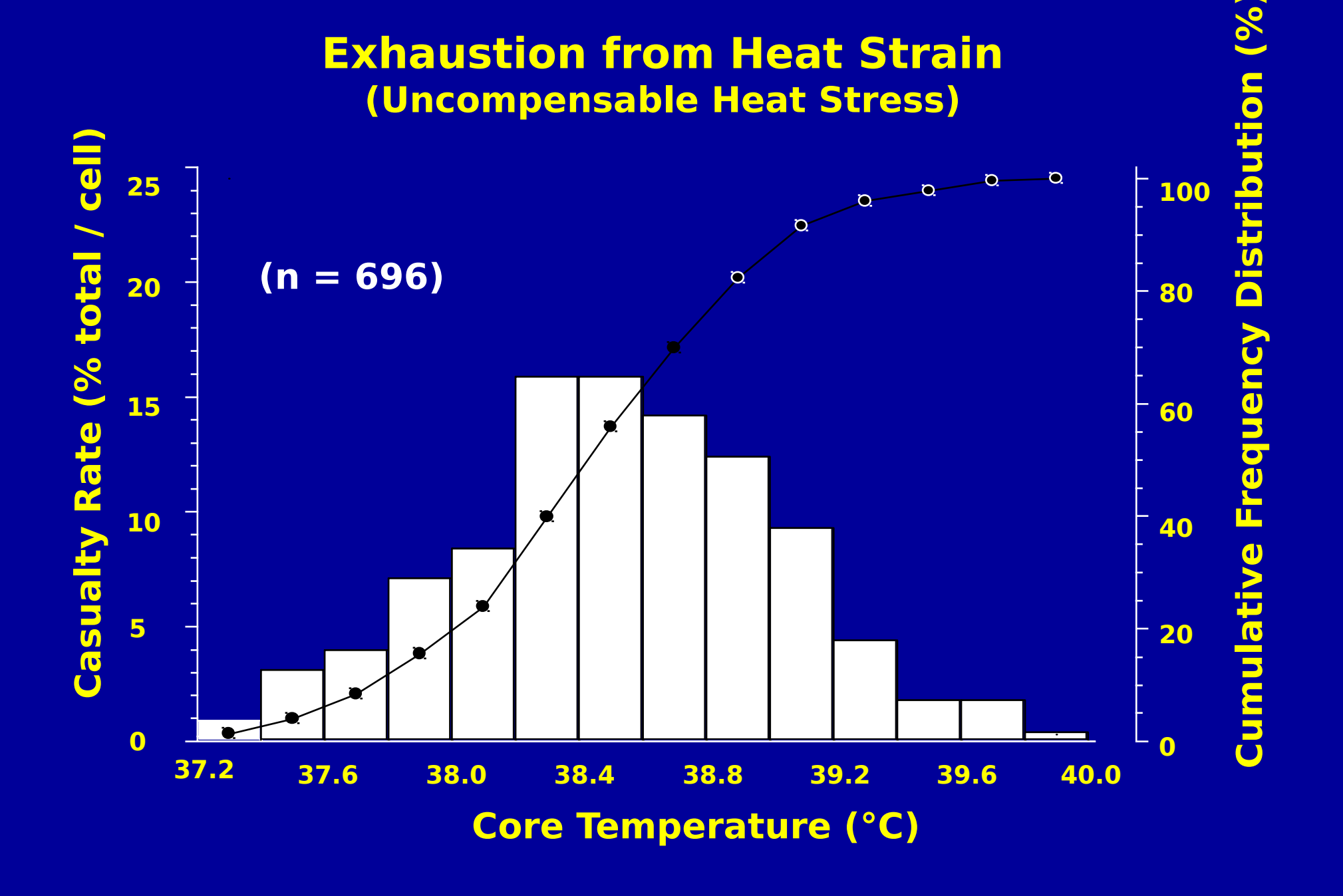


Sawka et al. EJAP 1985

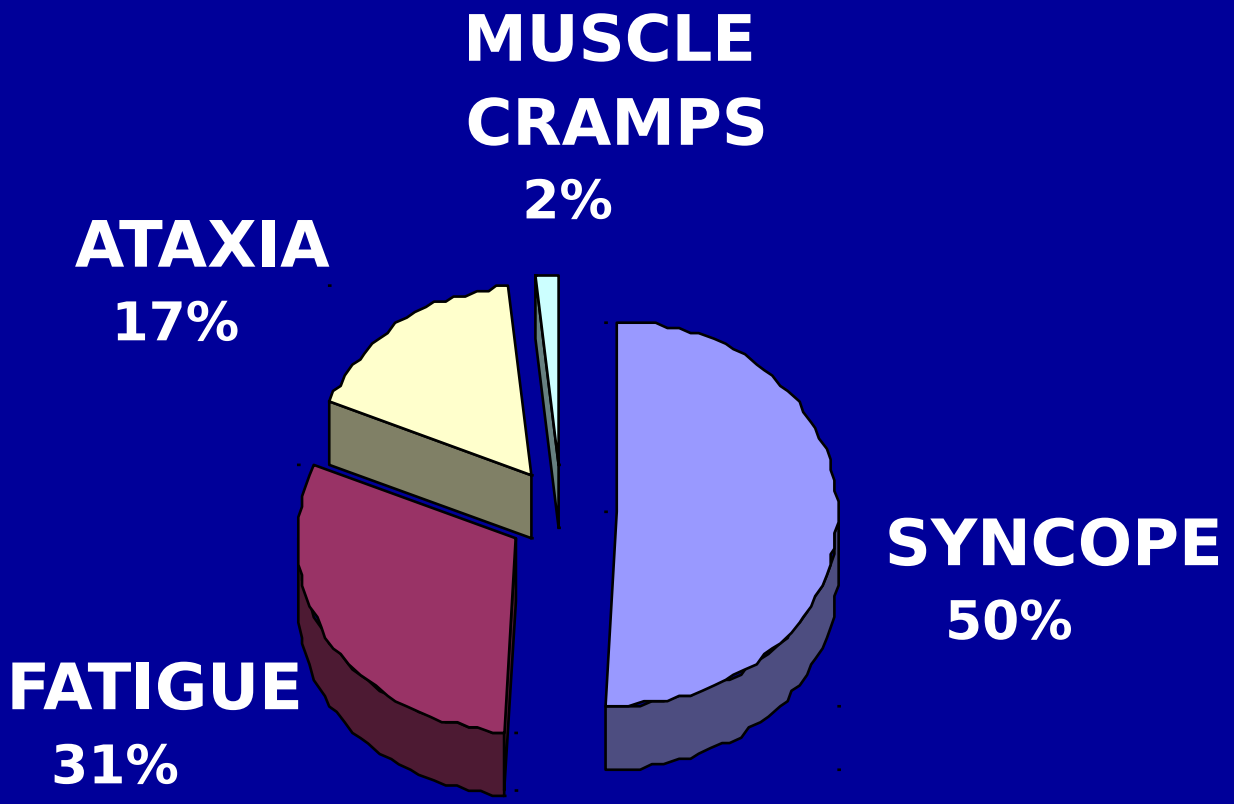
WHAT CORE TEMPERATURE CAN BE TOLERATED?

Relationships Between Core Temperature & Exhaustion from Heat Strain



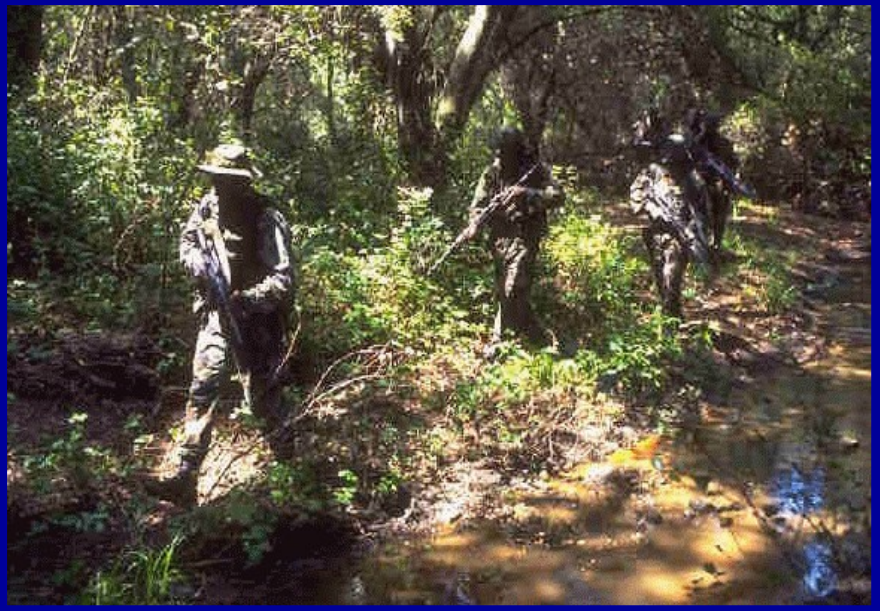

Exhaustion from Heat Strain
(Uncompensable Heat Stress)
(n = 696)
Casualty Rate (% total / cell)
Cumulative Frequency Distribution (%)
Core Temperature (°C)
0
5
10
15
20
25
0
20
40
60
80
100
37.2
37.6
38.0
38.4
38.8
39.2
39.6
40.0

SYMPTOMS OF EXHAUSTION FROM HEAT STRAIN



(n = 59)

Heat Stress Management - *Heat Acclimation*



Actions of Heat Acclimation

Thermal Comfort - *Improved*

Core Temperature - Reduced
Sweating - Improved
- Earlier Onset
- Higher Rate
- Redistribution (Tropic)
- Hidromeiosis Resistance (Tropic)

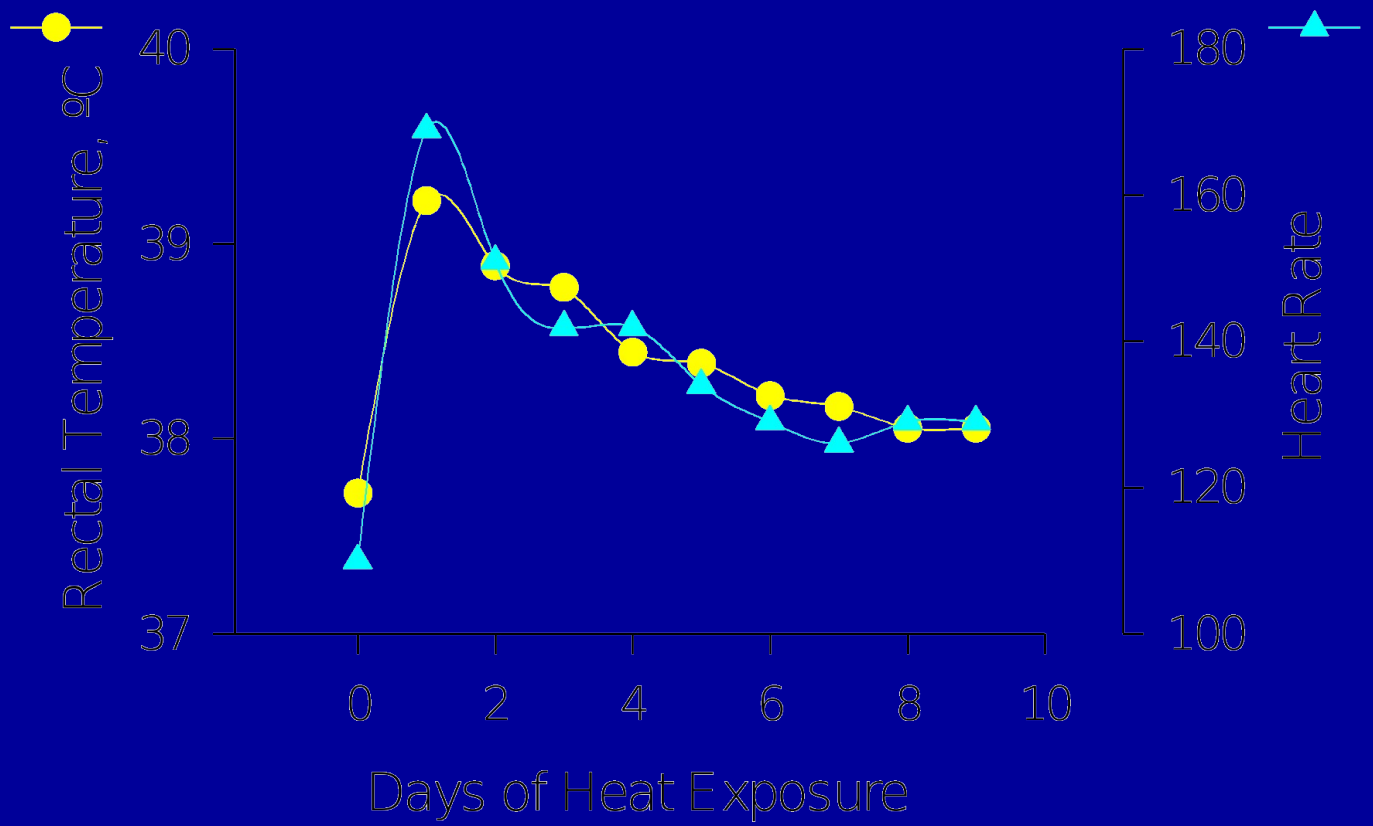
Skin Blood Flow - Increased
- Earlier Onset
- Higher Flow

Exercise Performance - I

Metabolic Rate - Lowered
Cardiovascular Stability - Improv
- Heart Rate - Lowered
- Stroke volume - Increased
- Blood Pressure - Better Defende

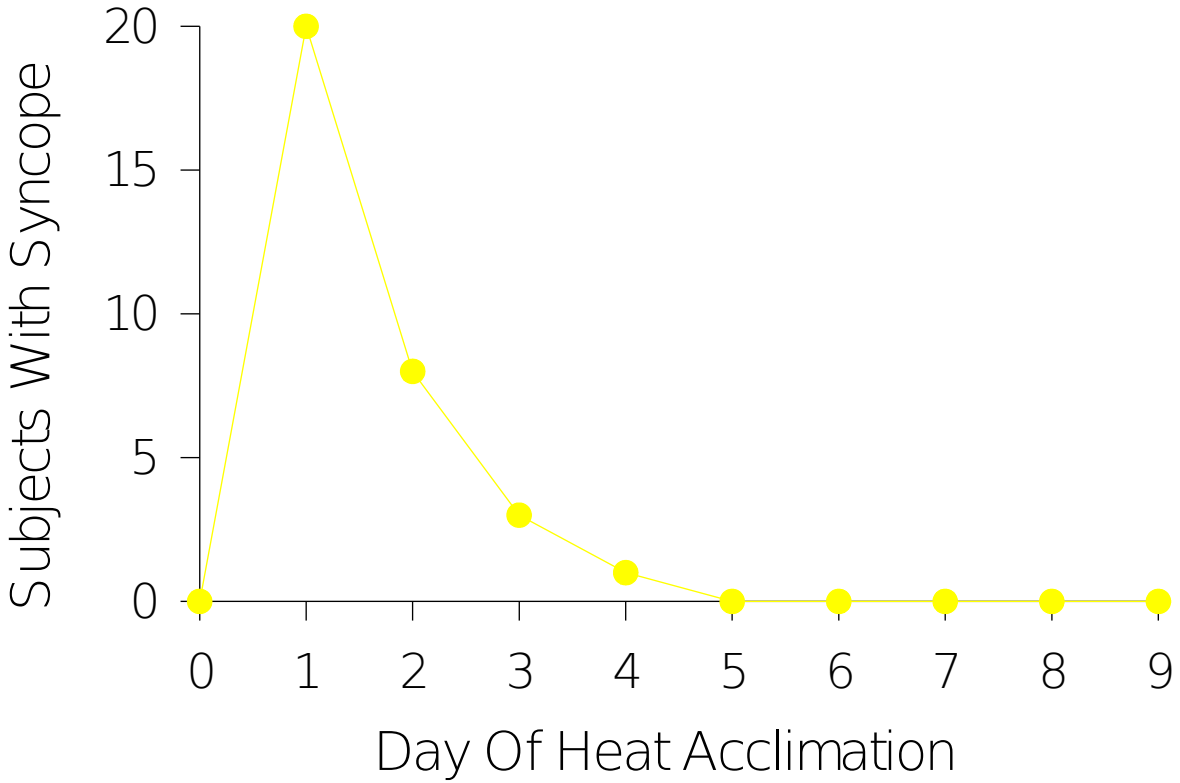
Fluid Balance- Improved
- Thirst- Improved
- Electrolyte Loss - Reduced
- Total Body Water - Increased
- Plasma Volume - Increased &
  Better Defend

Heat Acclimation Reduces Physiologic Strain



Lind and Bass, *Fed. Proc.* 22: 704, 1963

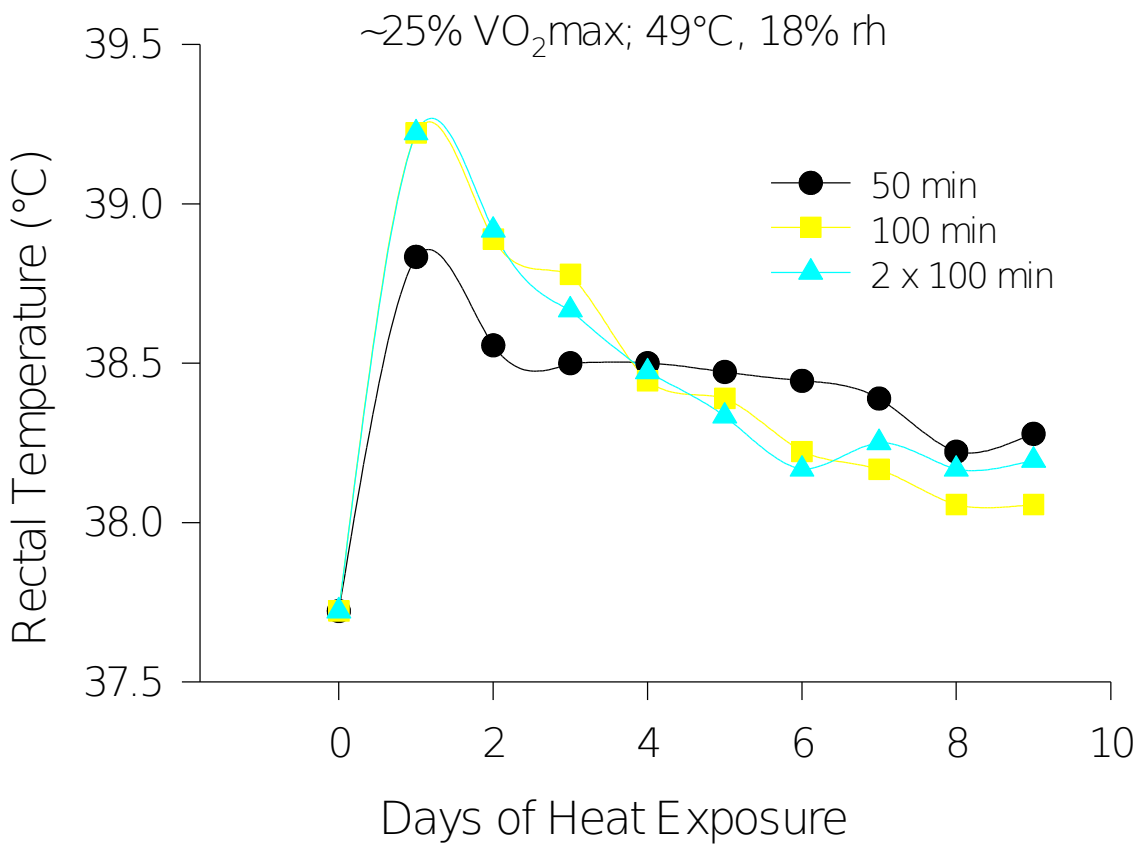
Heat Acclimation Reduces Heat Syncope



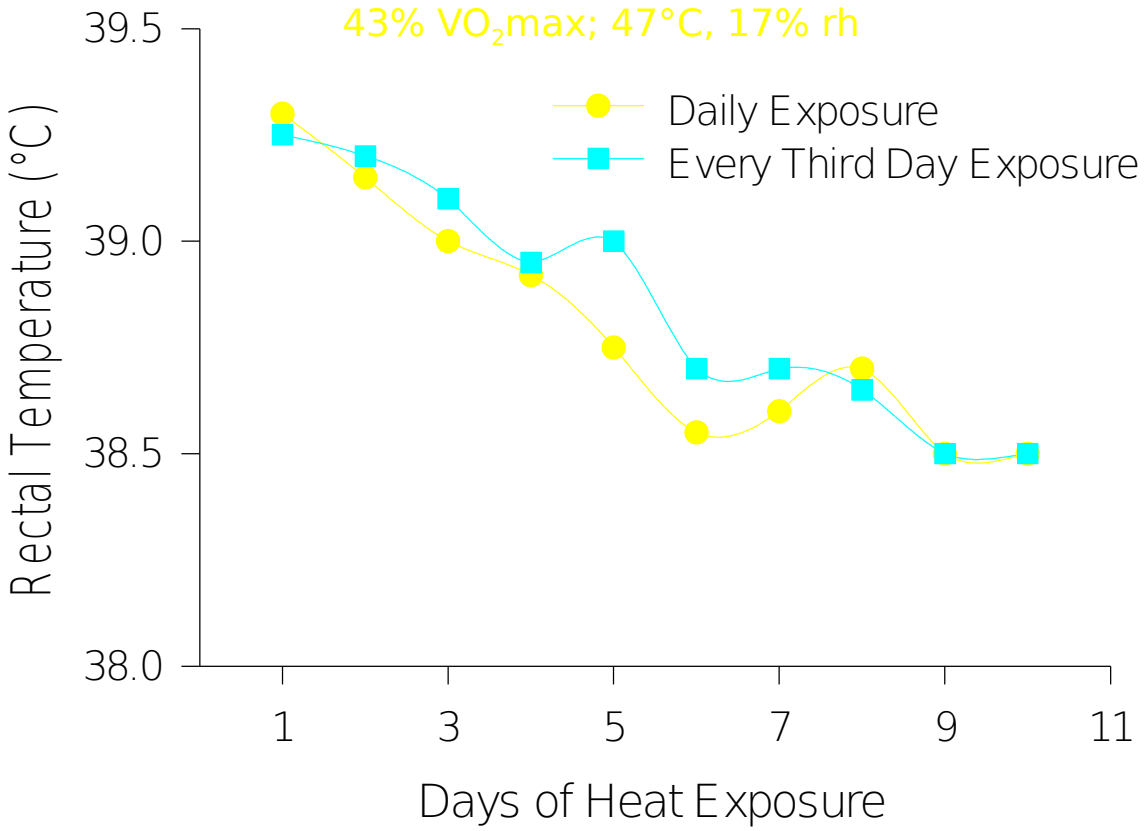
Heat Acclimation is Induced by:

- Repeated Heat Exposure Over Many Days
- Heat Stress Sufficient to Increase Body Temperature and Sweating
- Duration - 100 min / day
- Exposure - 4 to 14 days
- Specific to Heat Stress
  - Exercise / Rest
  - Intensity / Duration
  - Desert / Tropic

Duration of Heat Exposure

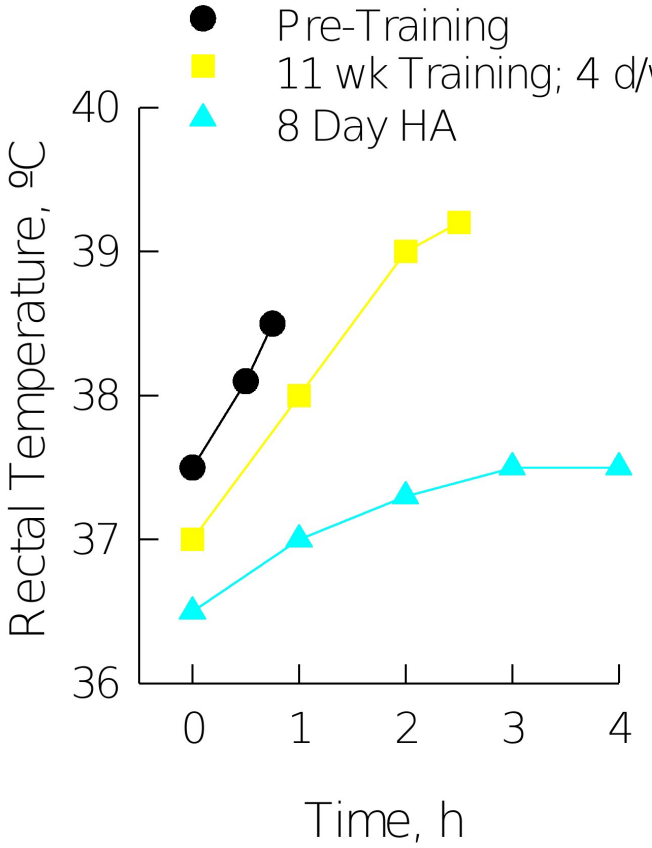


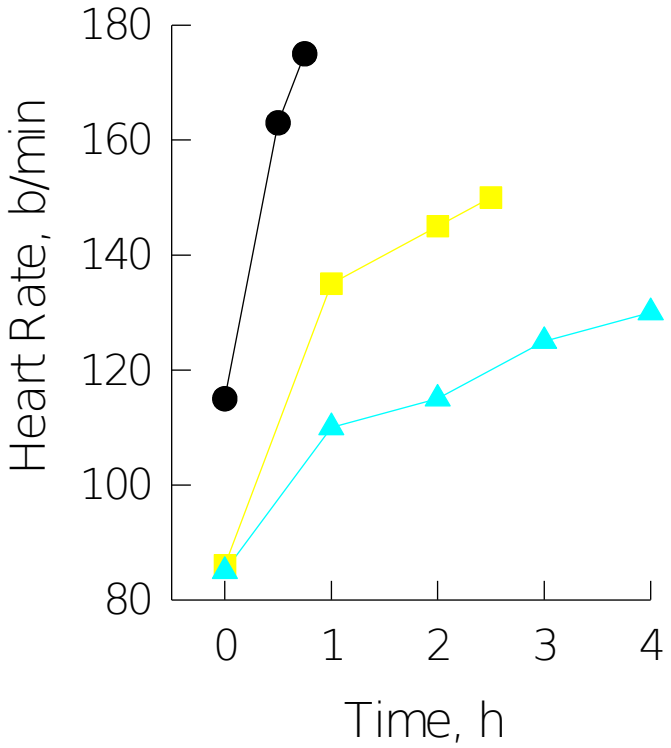
Frequency of Heat Exposure



Fein et al. ***Int J Biometeor*** 19: 41, 1975

Aerobic Training Induces Partial Heat Acclimation

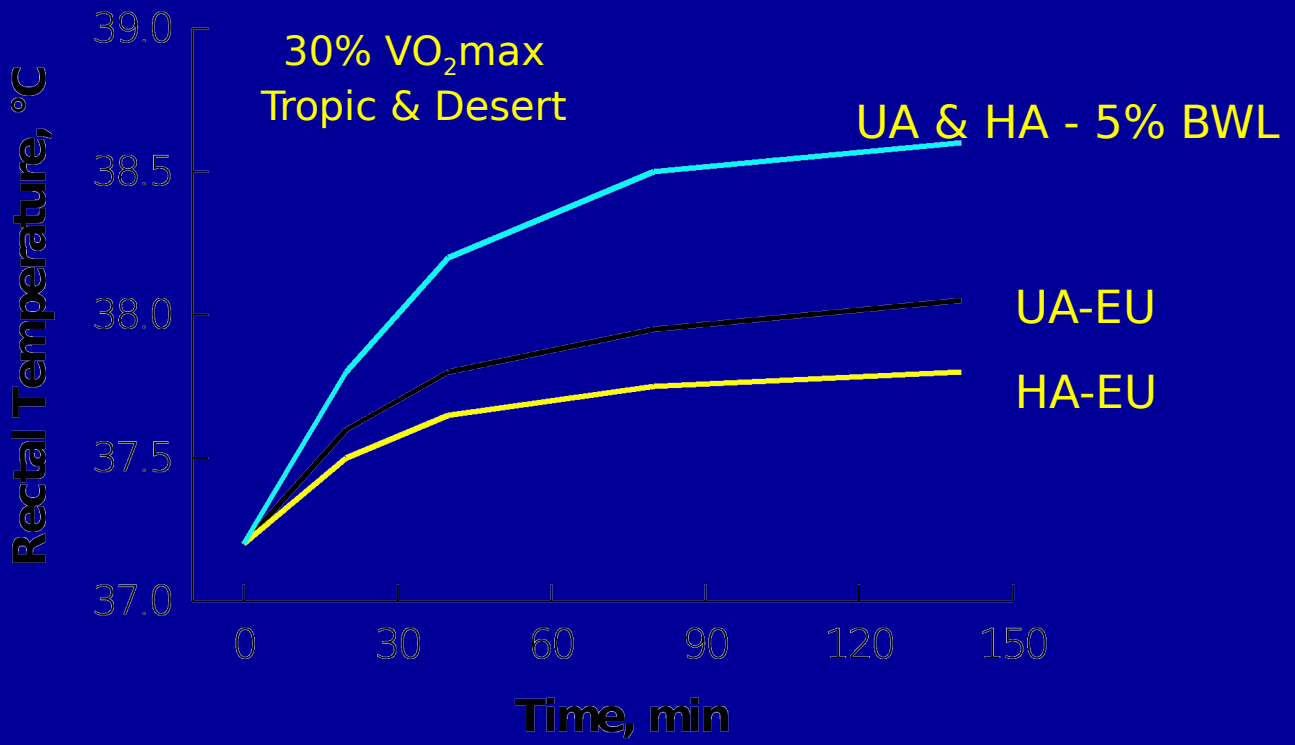




Heat Acclimation Benefits Undone by:

- **Dehydration**
- **Illness**
- **Skin Disorders (Rash, Sunburn)**
- **Sleep Deprivation**

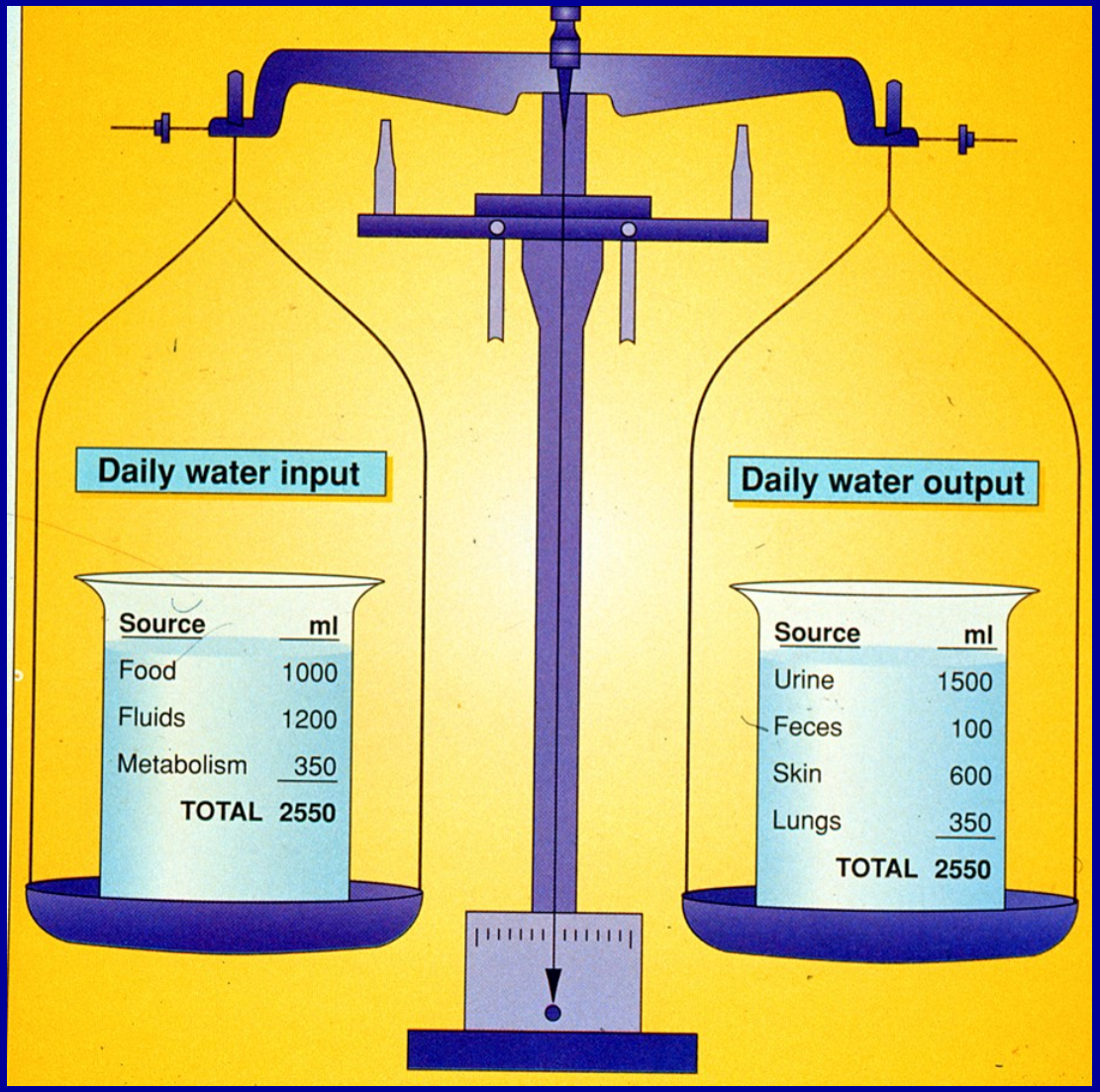
Dehydration Negates the Benefits of Heat Acclimation



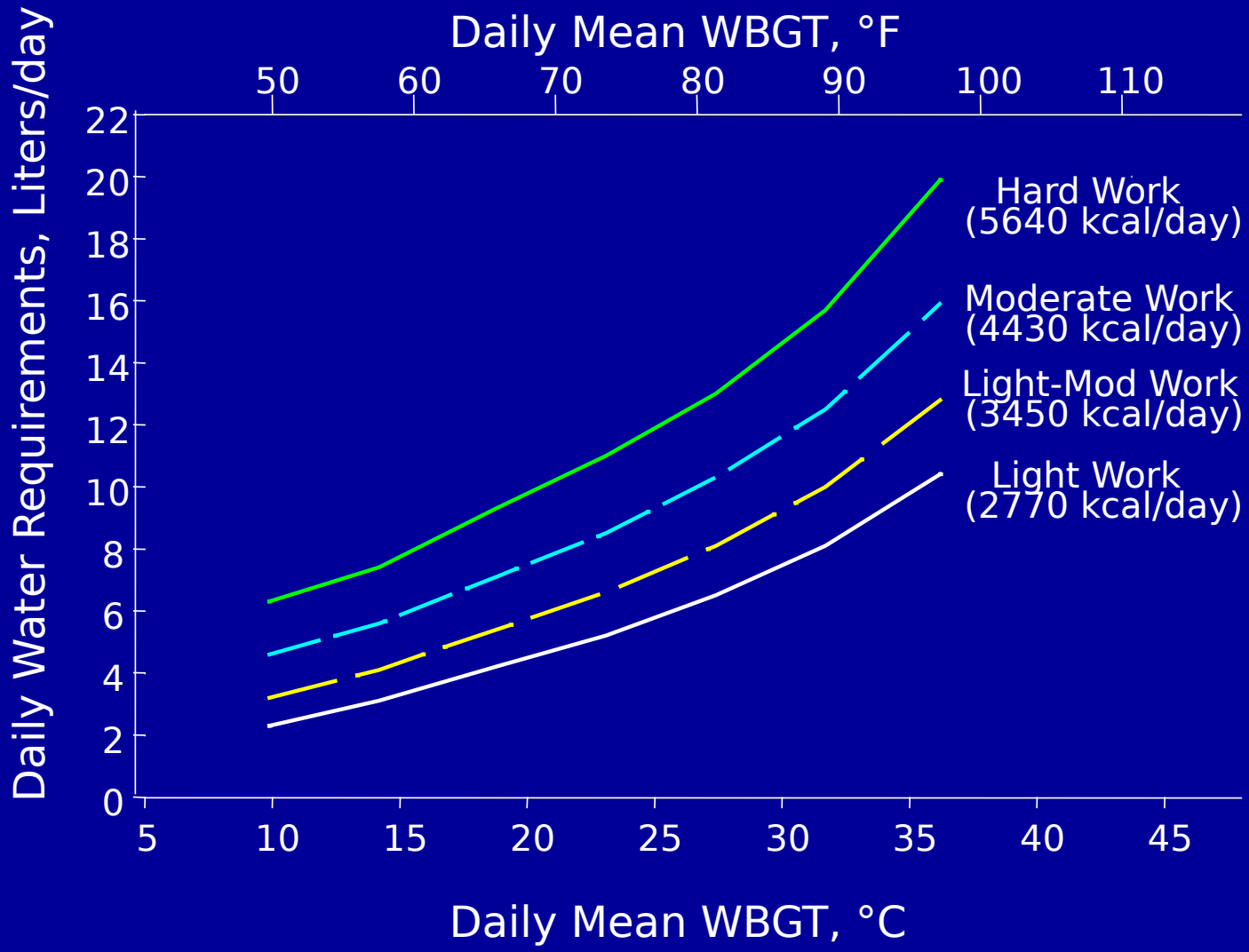
Sawka et al. *J Appl Physiol* 55: 1147, 1983

Heat Stress Management - Hydration

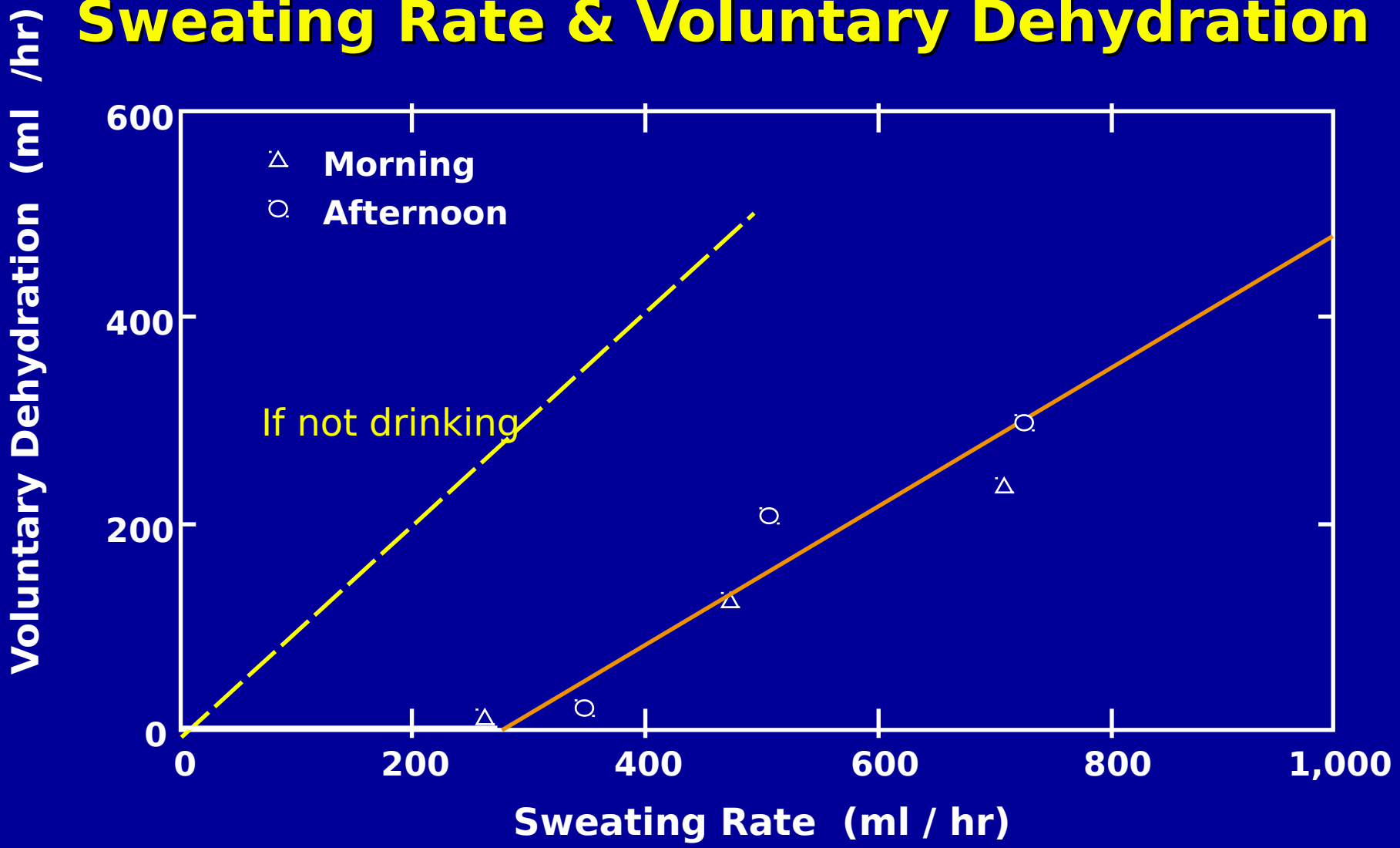
DAILY FLUID BALANCE



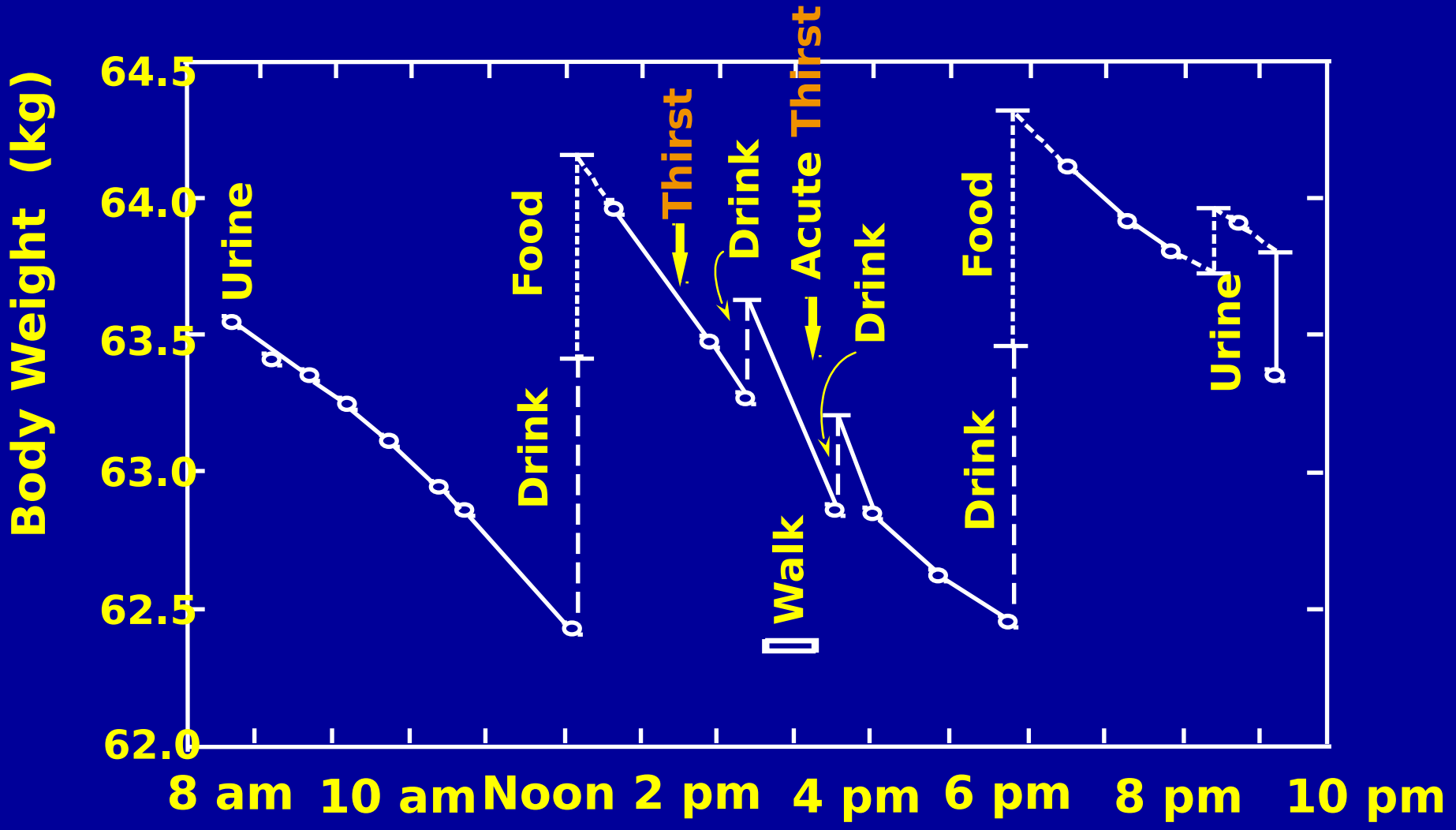
Daily Water Requirements



Sweating Rate & Voluntary Dehydration

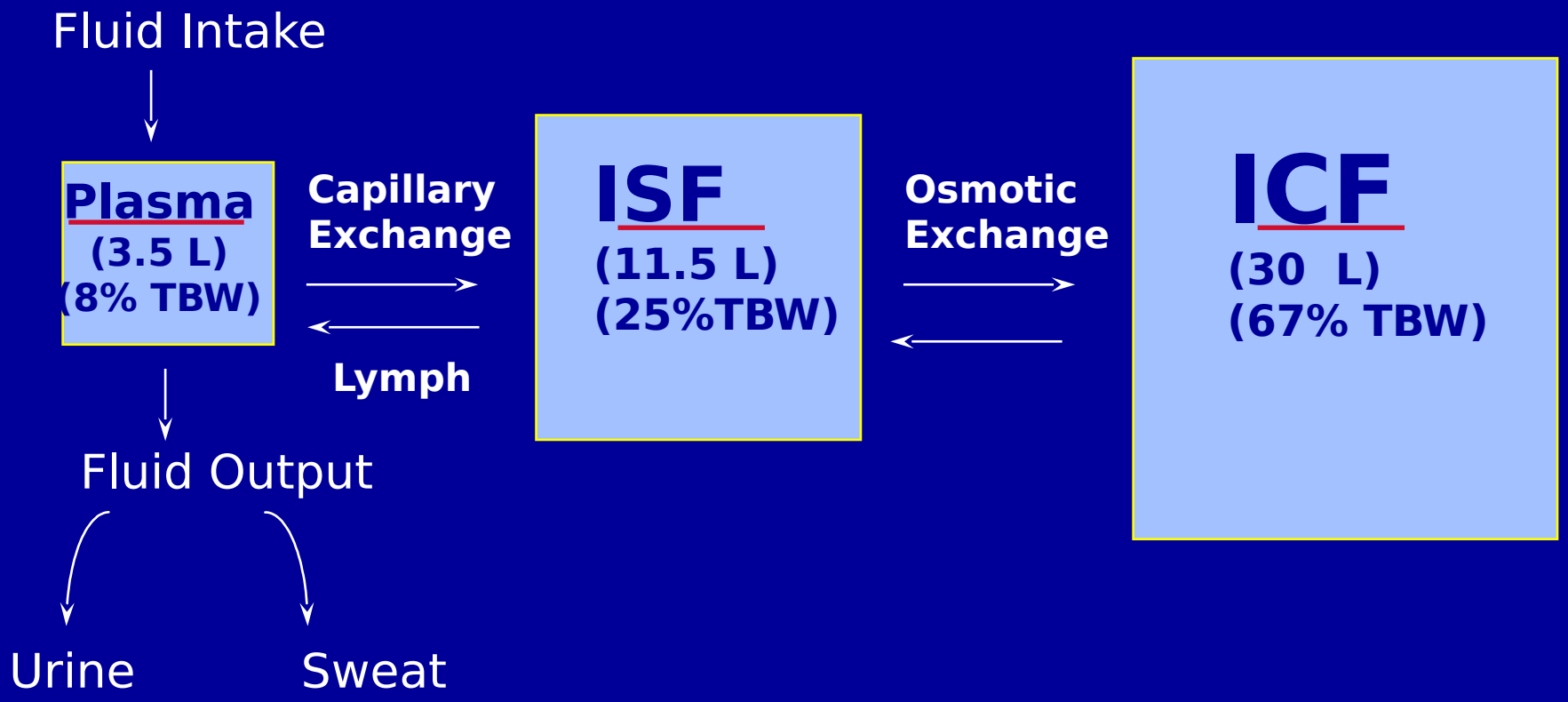


REHYDRATION MOSTLY OCCURS WITH MEALS

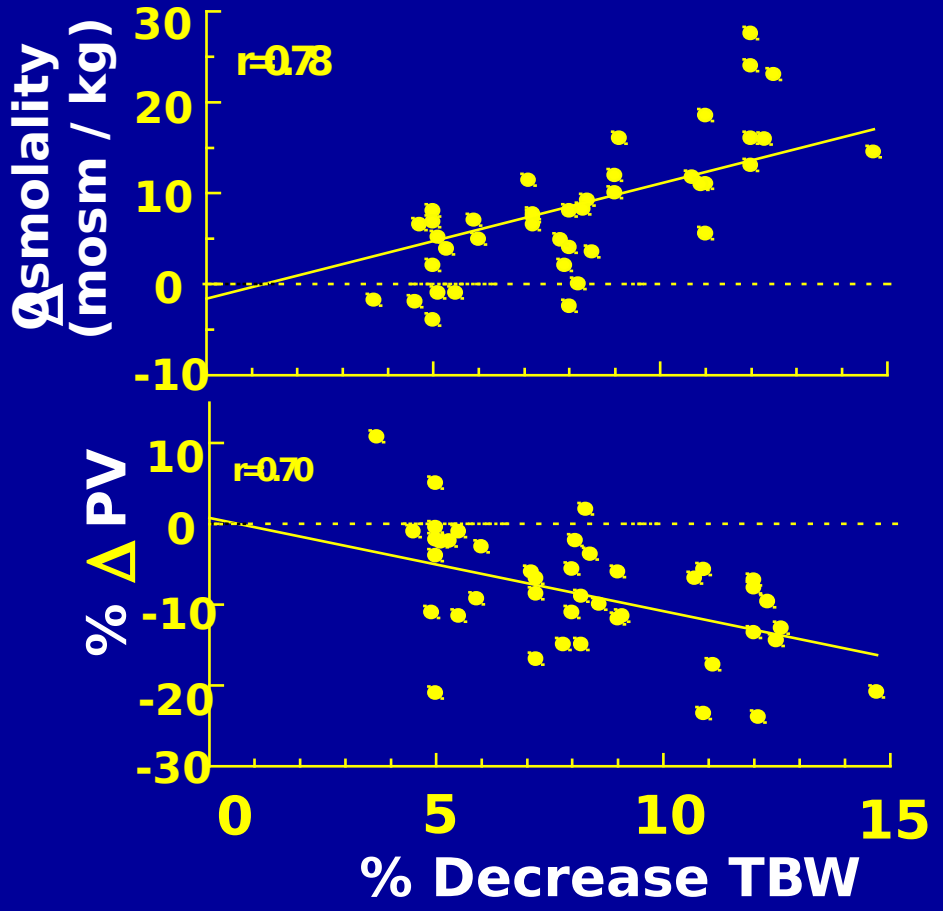


Adolph & Associates, Physiol. Man in Desert, 1947

WATER VOLUMES & EXCHANGE MECHANISMS BETWEEN FLUID COMPARTMENTS

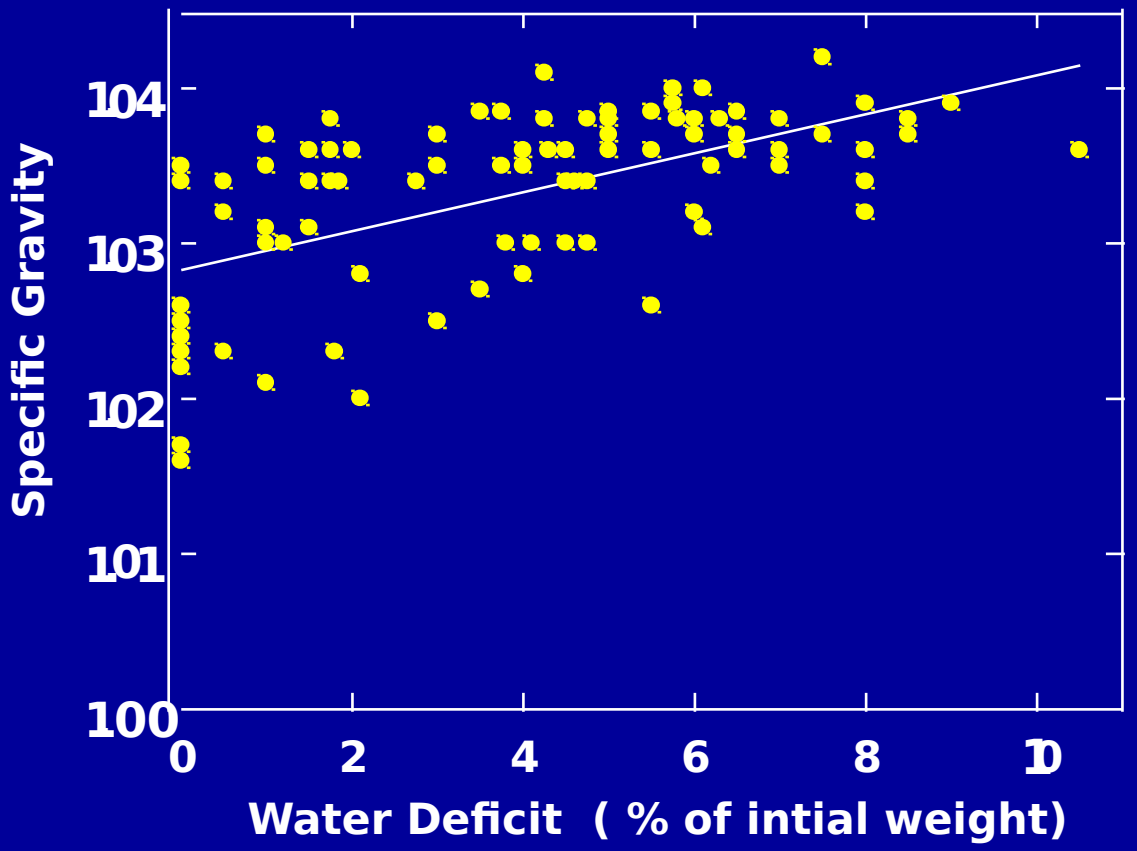


HYPOHYDRATION ALTERS PLASMA TONICITY & VOLUME AT REST



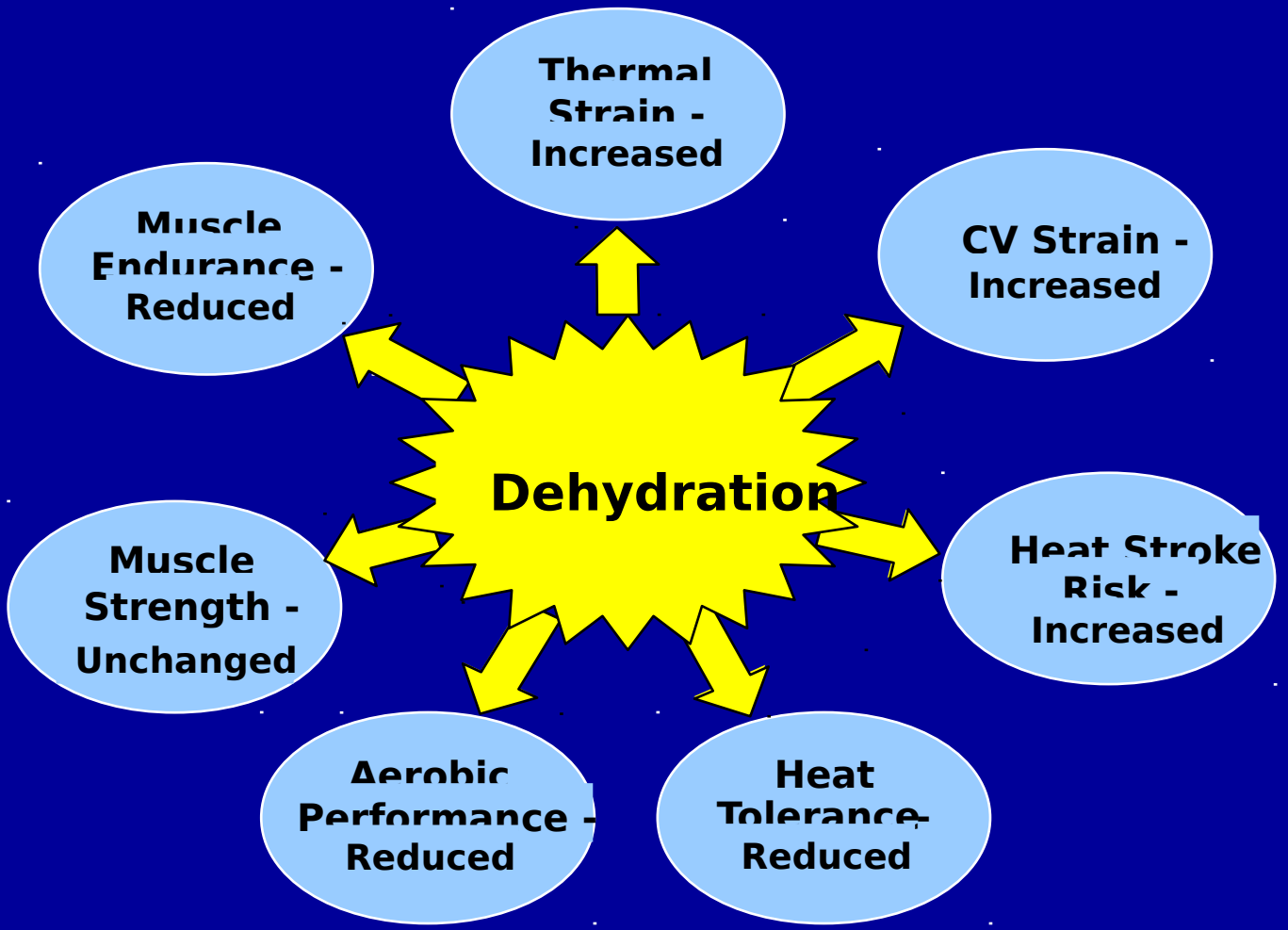
Sawka et al. Body Fluid Balance Exerc. & Sport 1996

Dehydration & Urine Specific Gravity



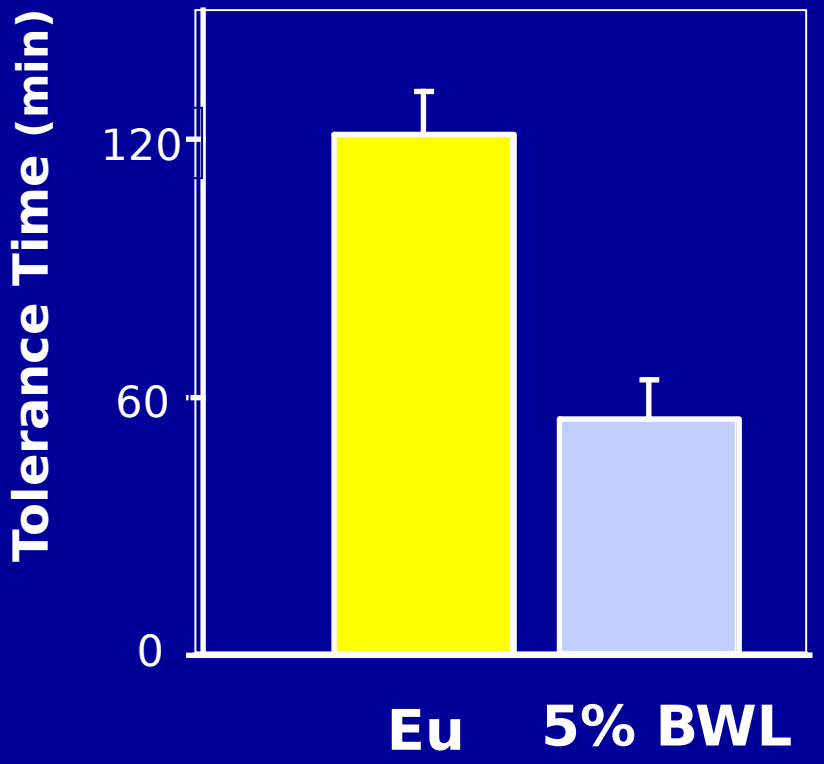
Adolph & Associates, Physiol. Man in Desert, 1947

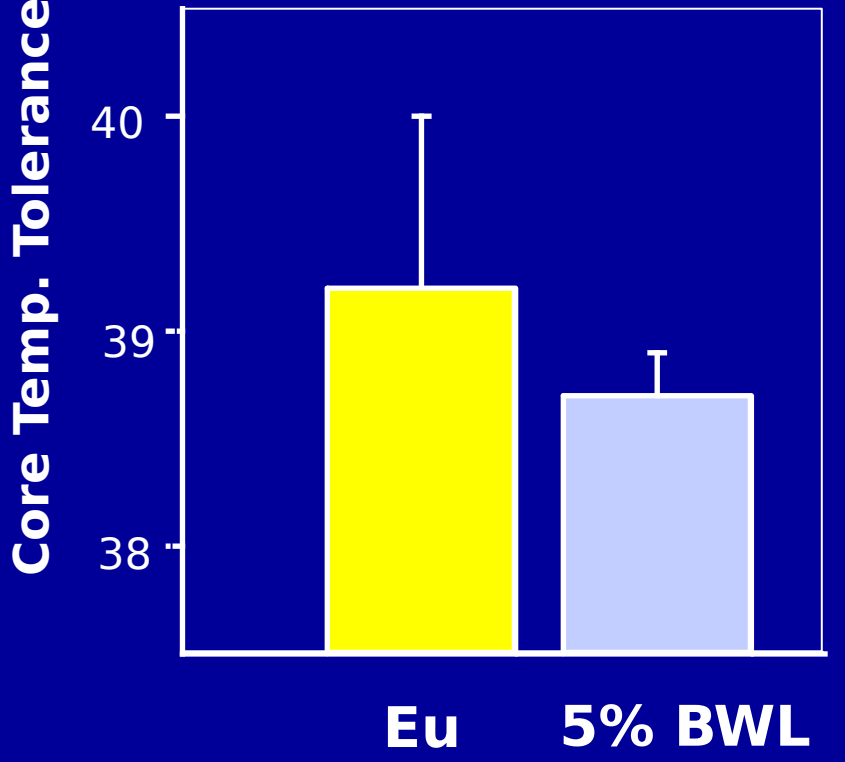
Impact of Dehydration



DEHYDRATION DECREASES SUBMAXIMAL EXERCISE- HEAT TOLERANCE

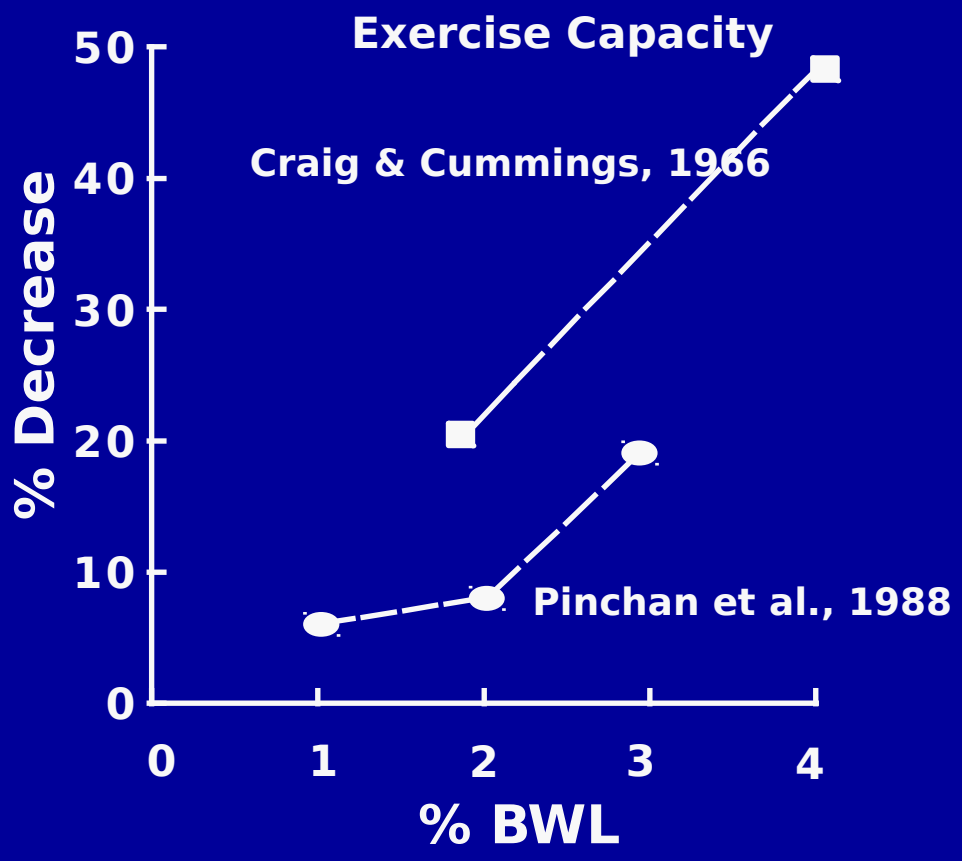
47% $\dot{V}O_2$max; 49°C, 20% rh

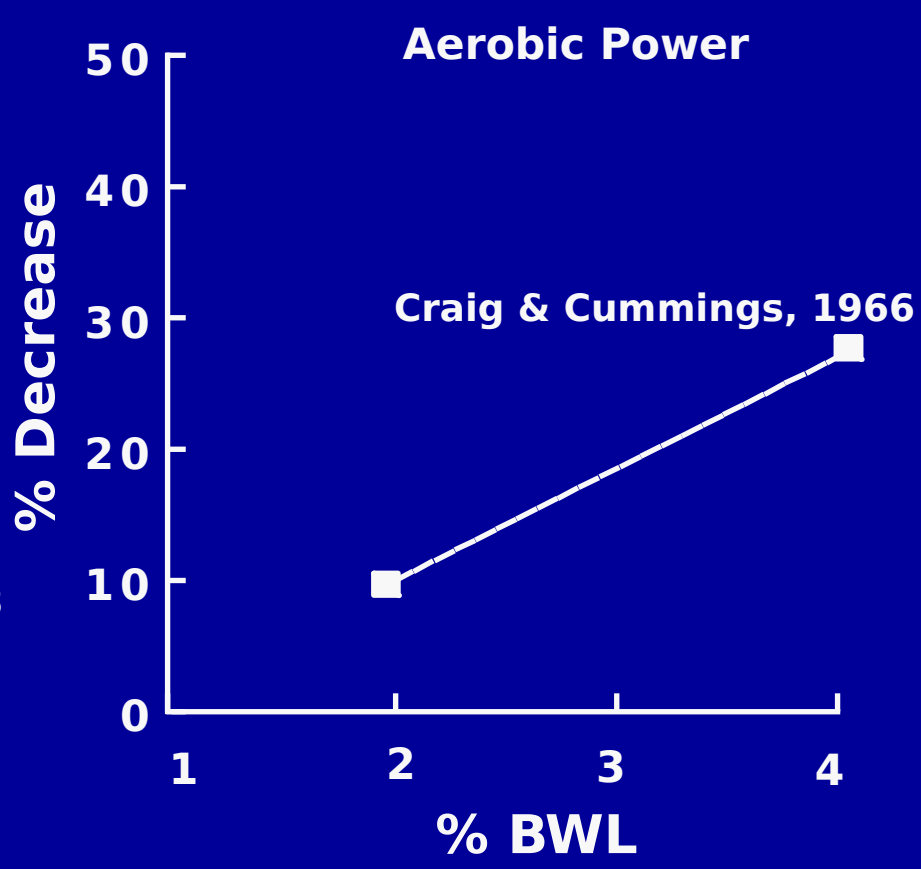




Sawka et al. JAP, 1992

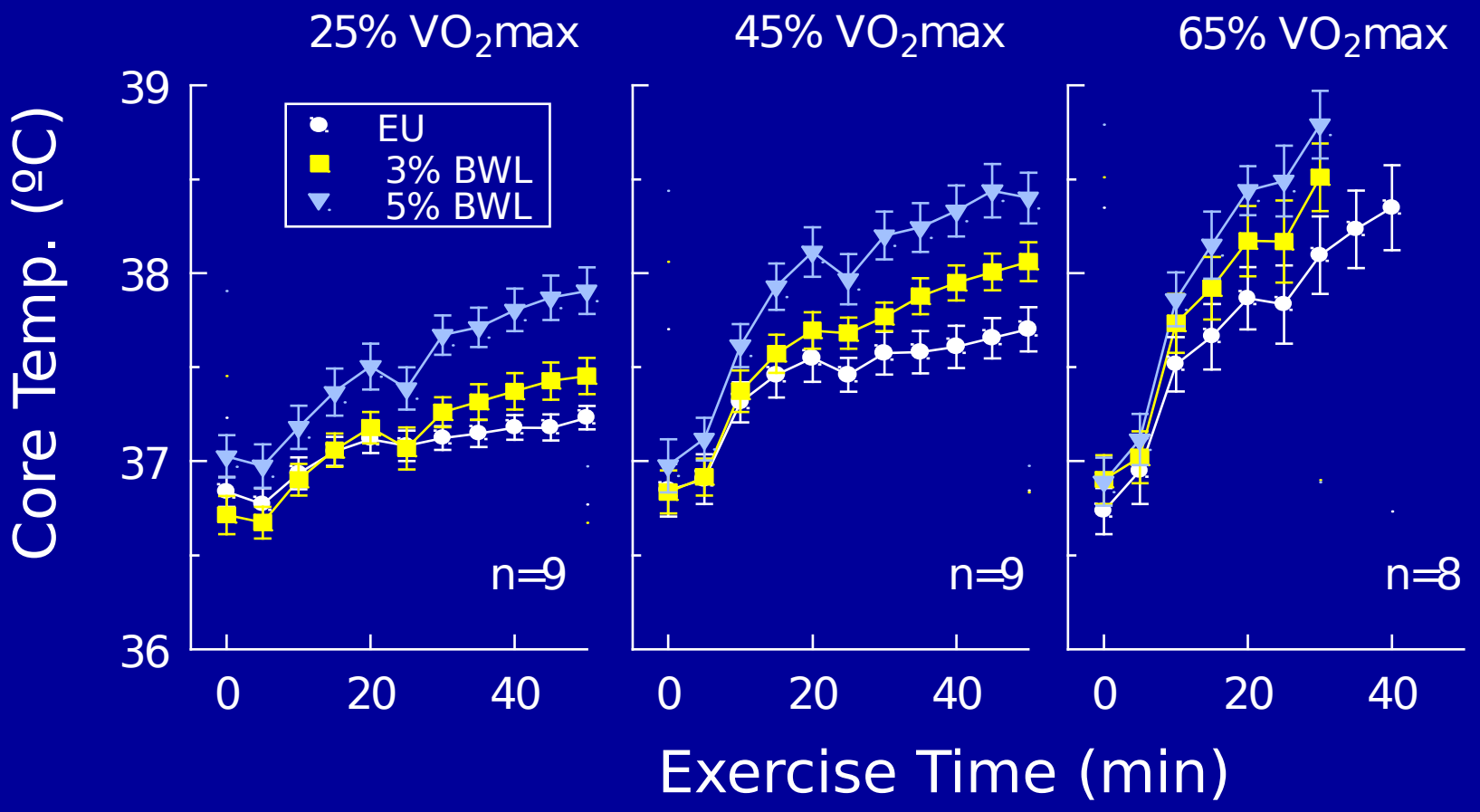
Dehydration Reduces Maximal Exercise In The Heat





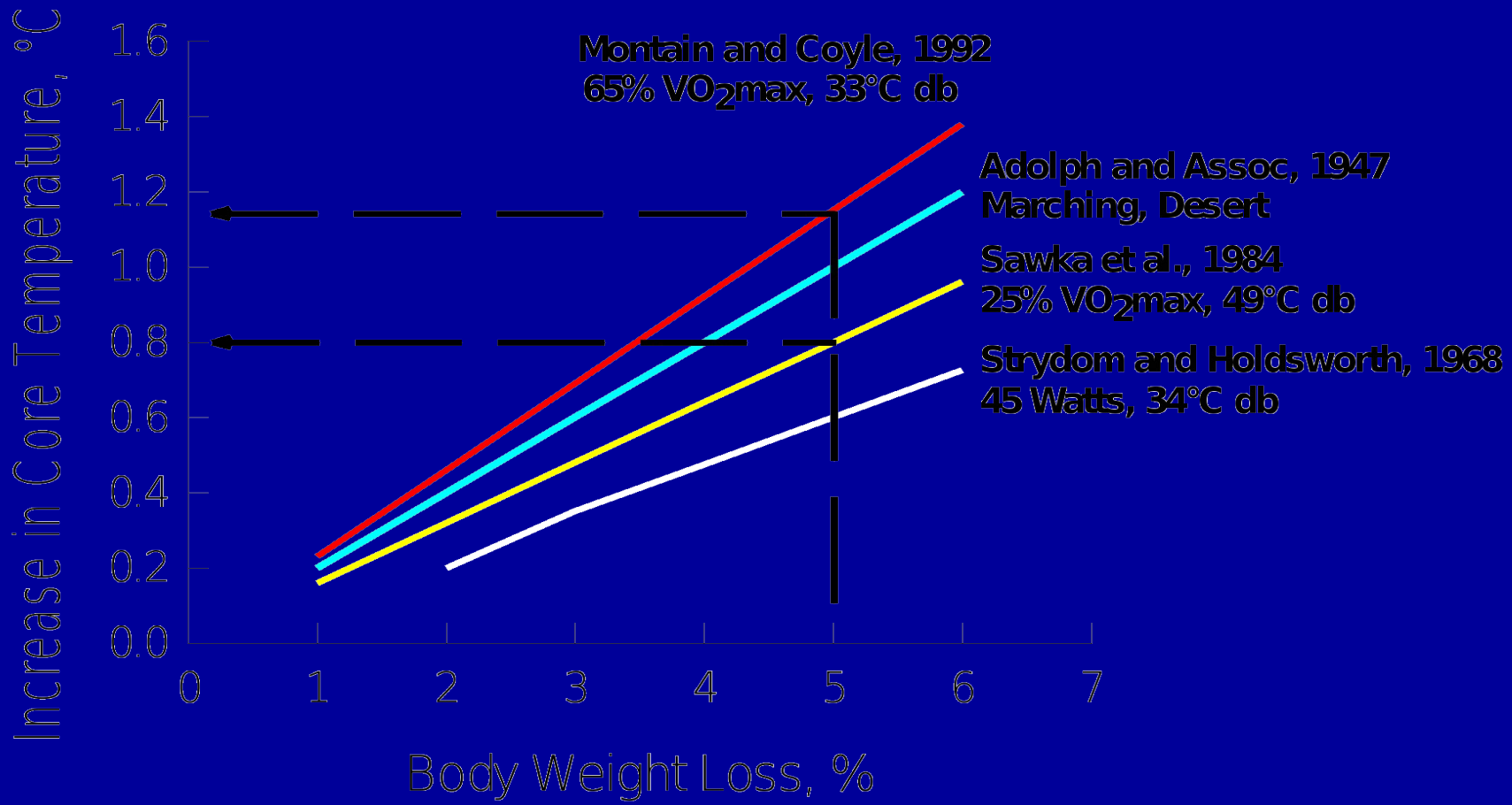
DEHYDRATION INCREASES CORE TEMPERATURE

(30ºC, 50% rh)

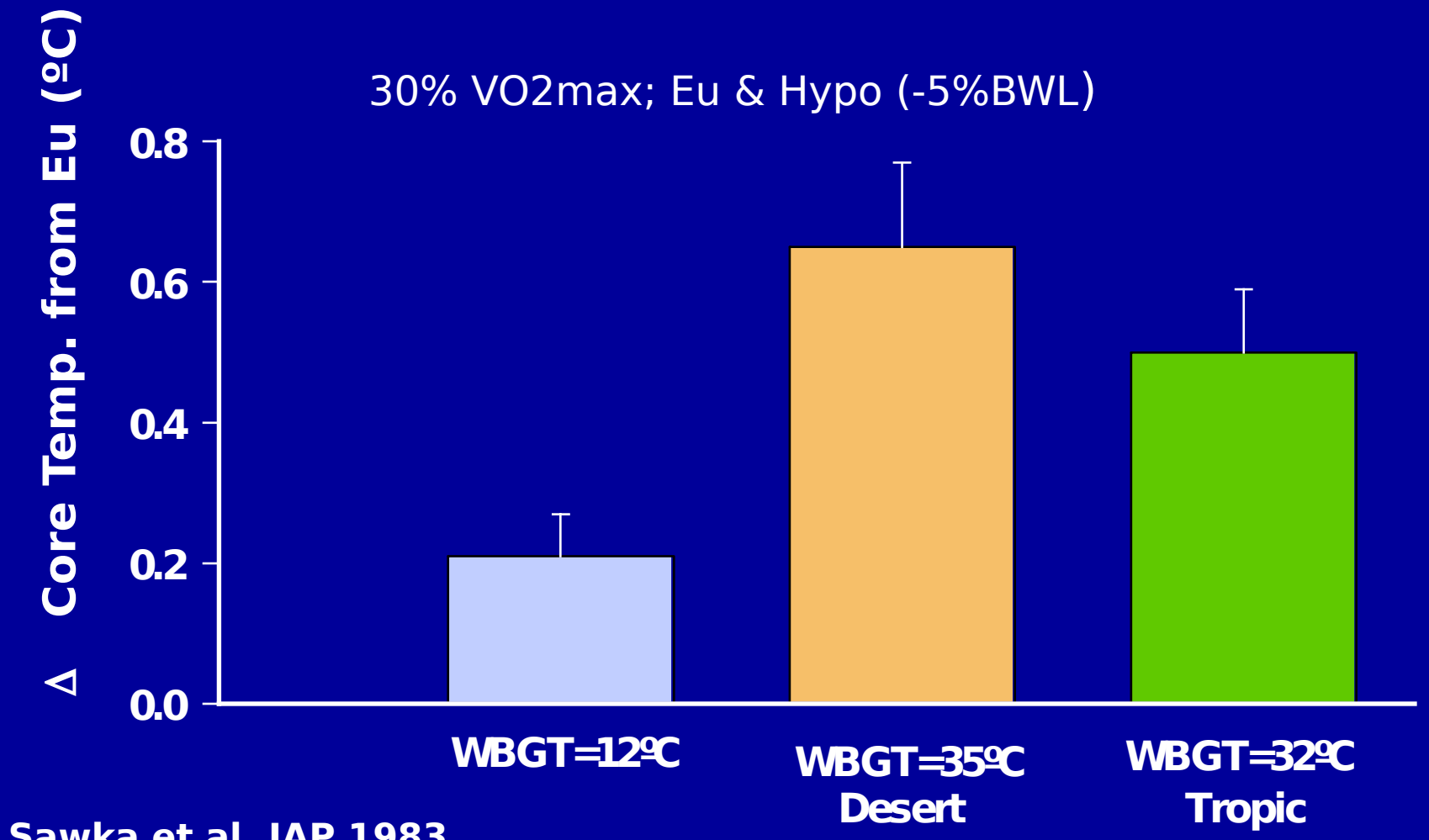


Montain et al. Int. J. Sports Med., 1998

DEHYDRATION INCREASES CORE TEMPERATURE

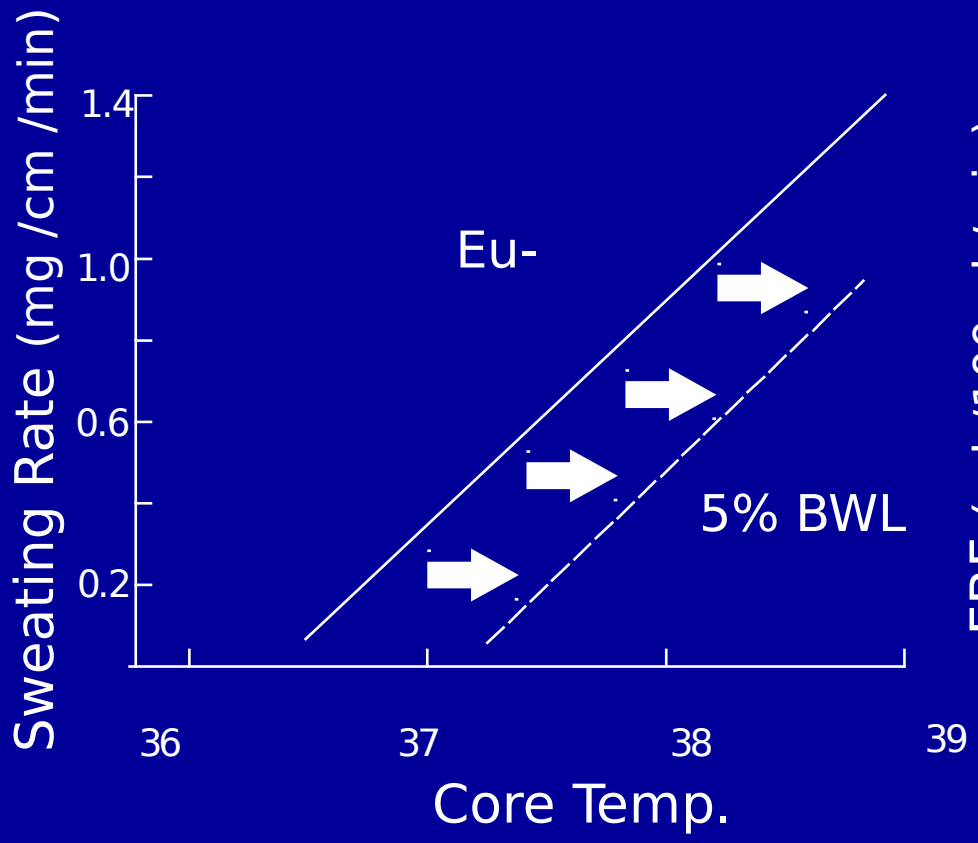


CLIMATE EFFECTS ON DEHYDRATION MEDIATED CORE TEMPERATURE RISE

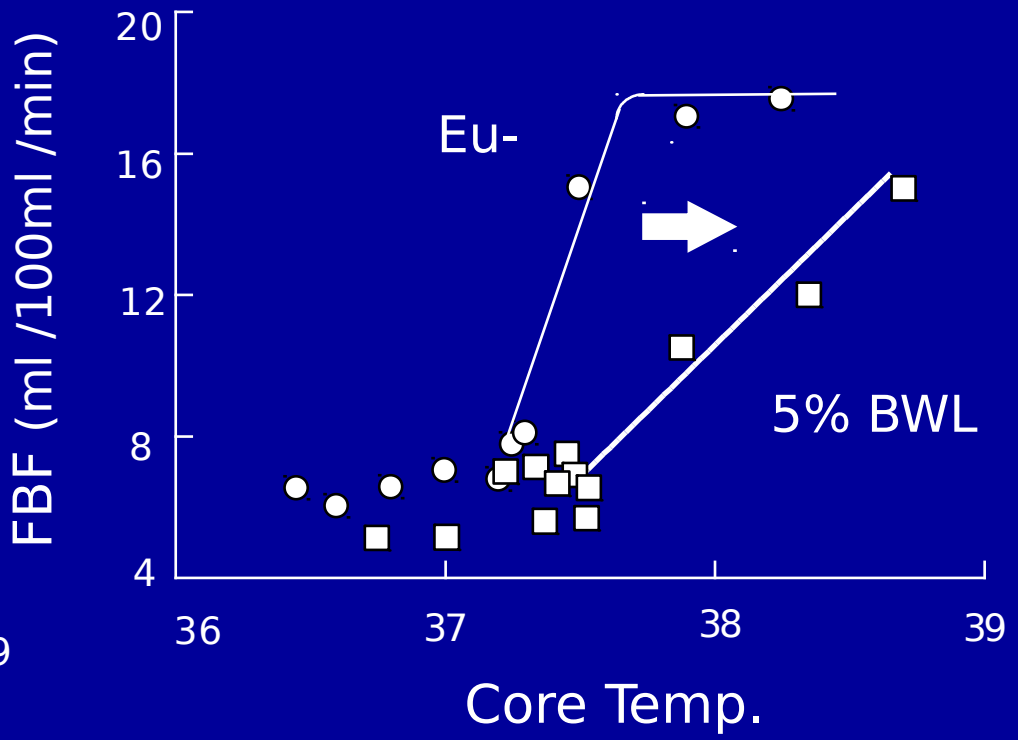


Sawka et al. JAP 1983

DEHYDRATION REDUCES SWEATING & SKIN BLOOD FLOW DURING EXERCISE- HEAT STRESS



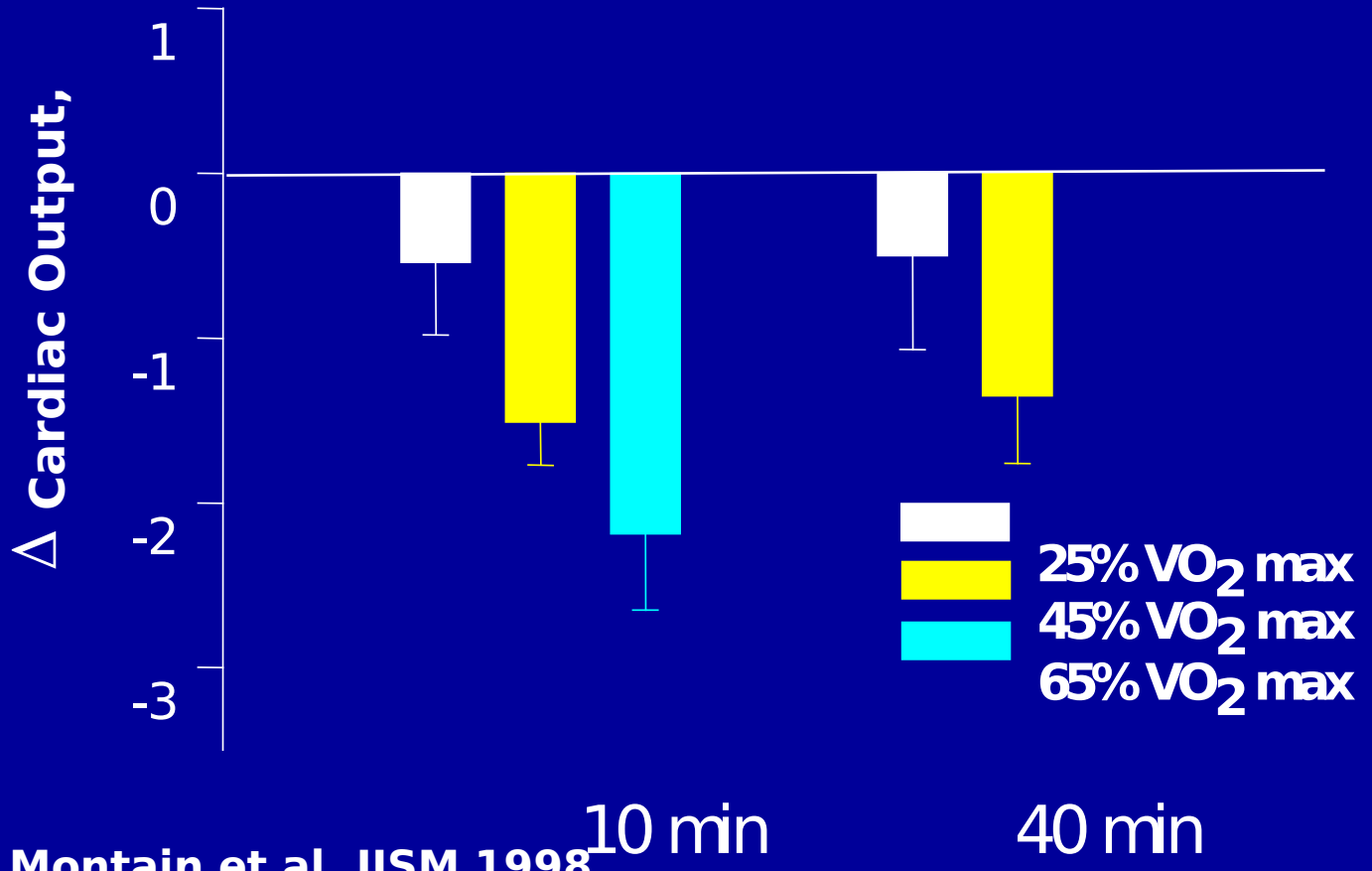
Sawka et al, AJP 1989



Kenney et al, JAP 1990

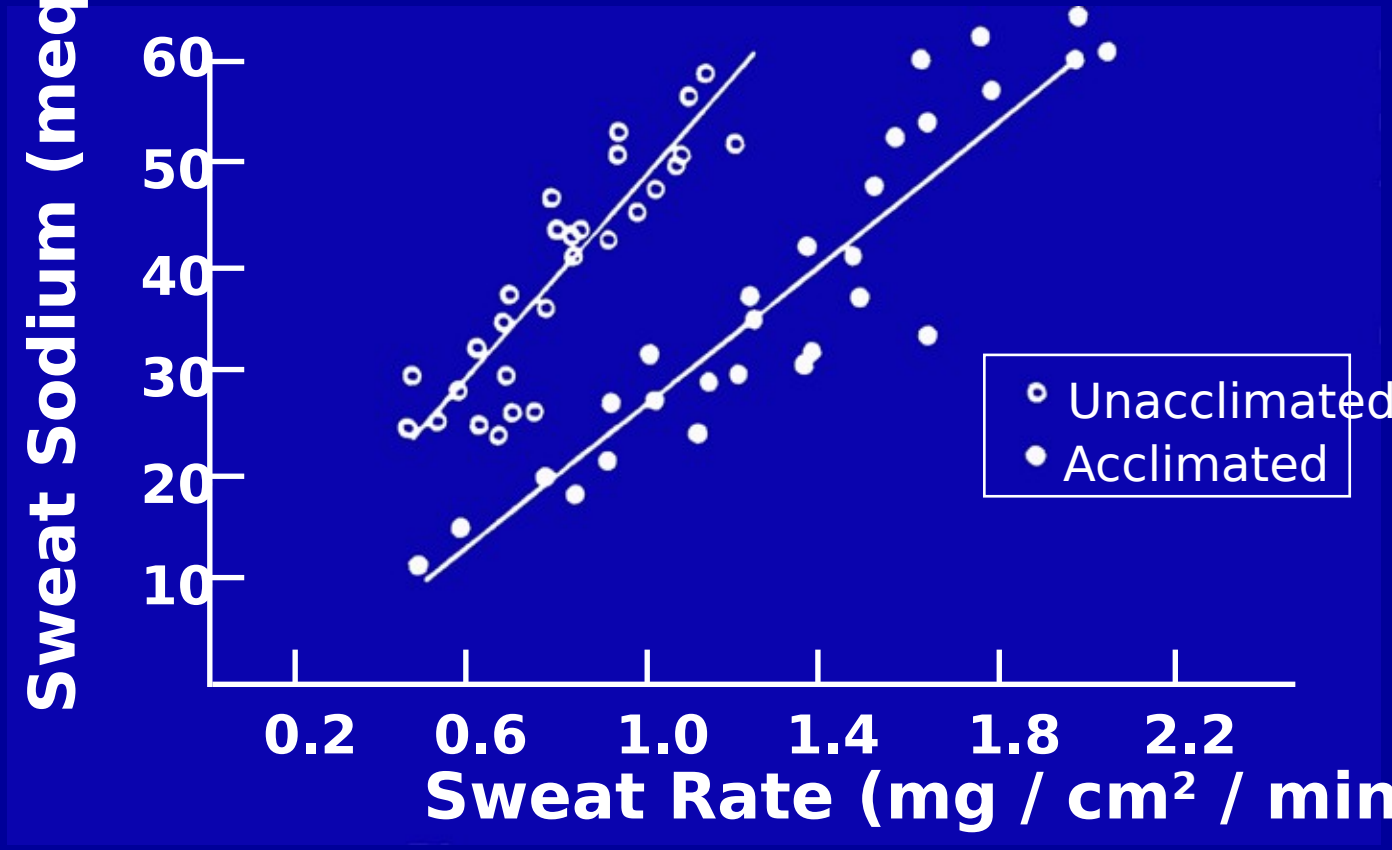
CARDIAC OUTPUT FALLS WITH EXERCISE INTENSITY WHEN DEHYDRATED

(5% BWL)



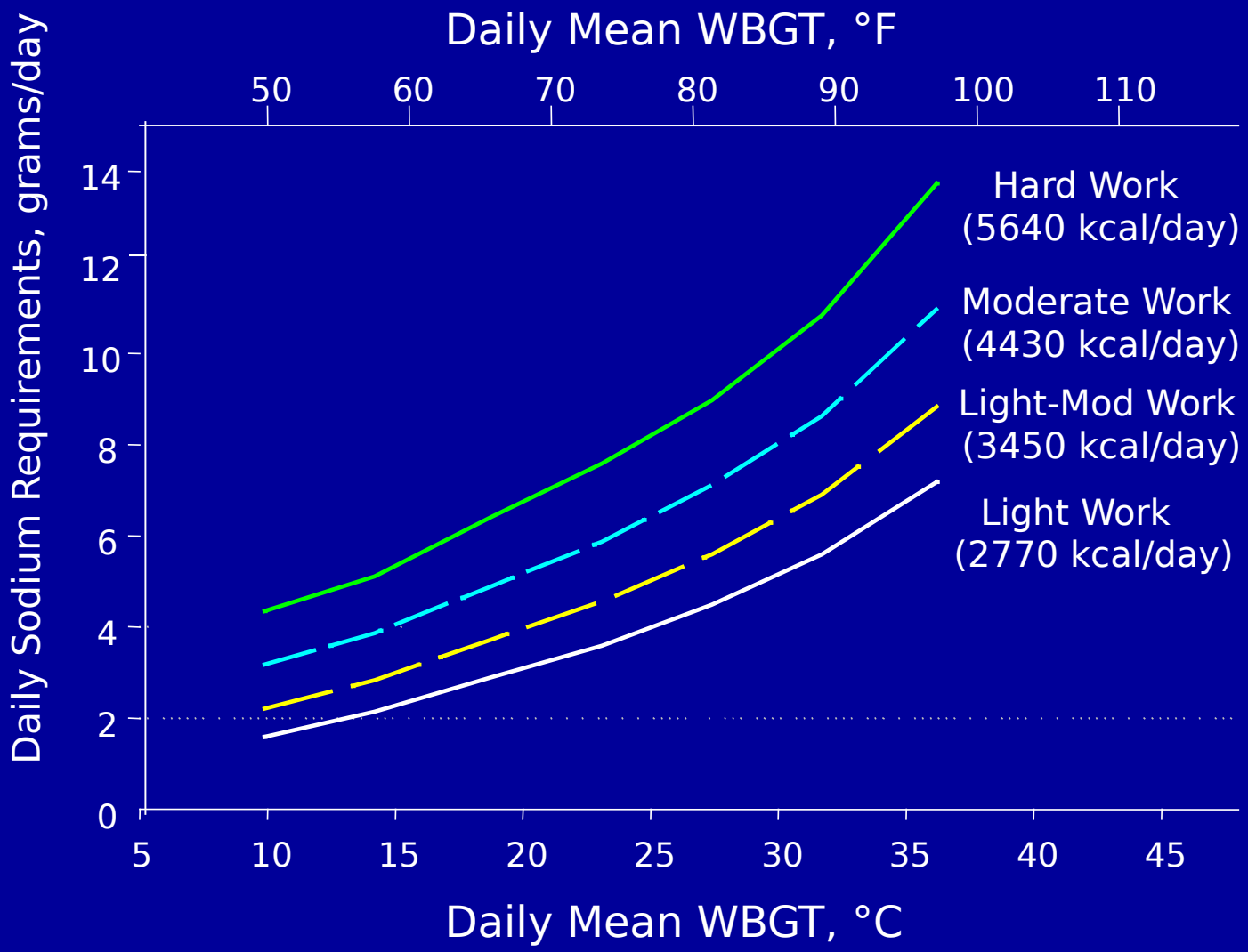
Montain et al. IJSM 1998

HEAT ACCLIMATION & SWEAT RATE EFFECTS ON SODIUM LOSS



Alan & Wison, JAP 1971

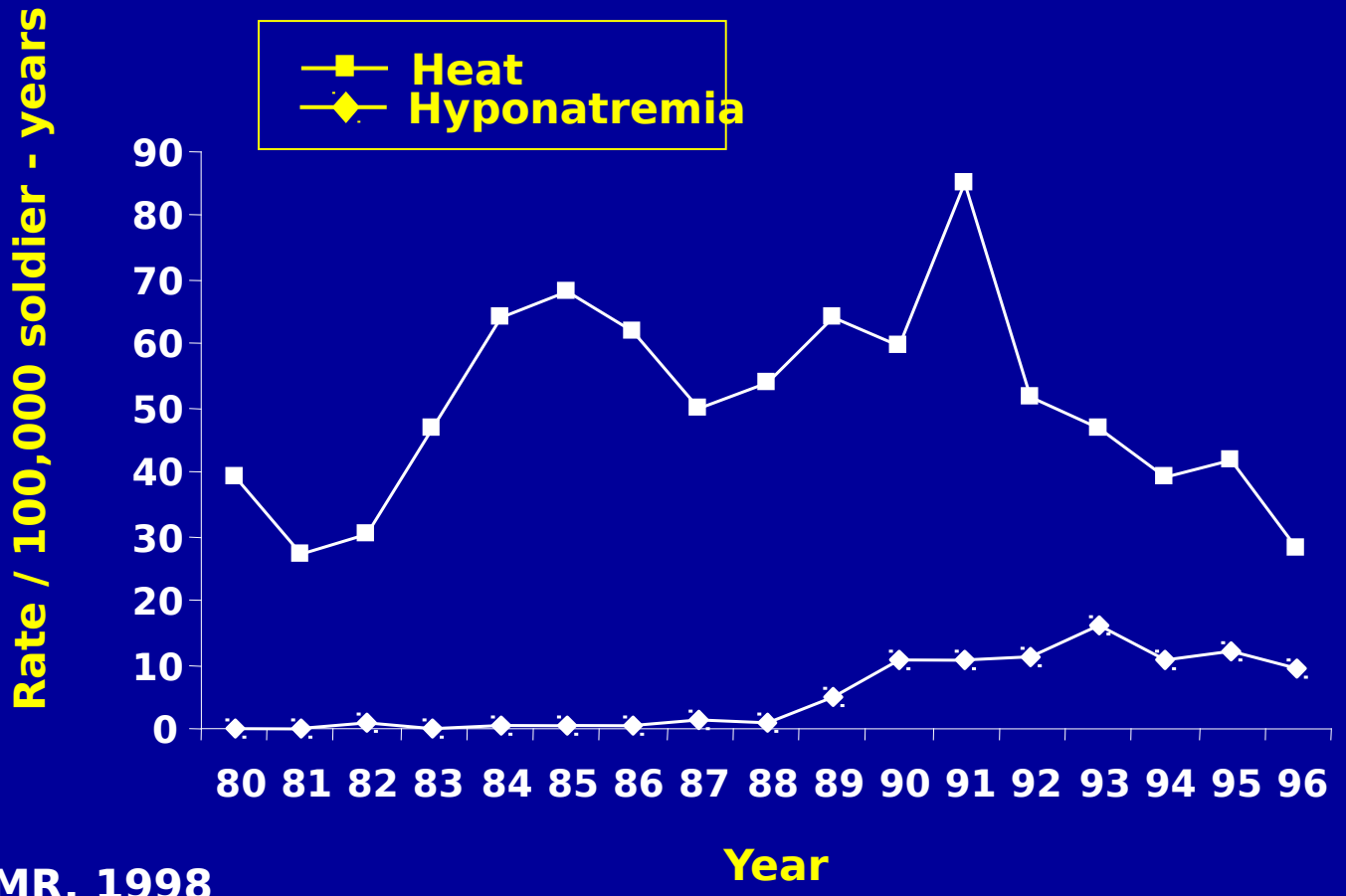
Daily Sodium Requirements



Sodium Balance in Soldiers

- **Sweat sodium losses in hot weather**
  - **~1 to 12 g / d**
- **MRE sodium ~3.4 g each**
  - **~1.8 g sodium (~4.6g NaCL) / MRE**
  - **~1.6 g sodium (~4.0 g NaCl) / salt packet**
- **Consumption of 3 MRE**
  - **10.2 g maximum**
  - **5.4 g if salt packet <u>not</u> consumed**
- **Garrison meal sodium consumption**
  - **2.3 - 9.5 g / day (95% confidence limits)**

Hospitalizations due to Excessive Heat & Hyposmolality / Hyponatremia in the Army 1980 - 1996



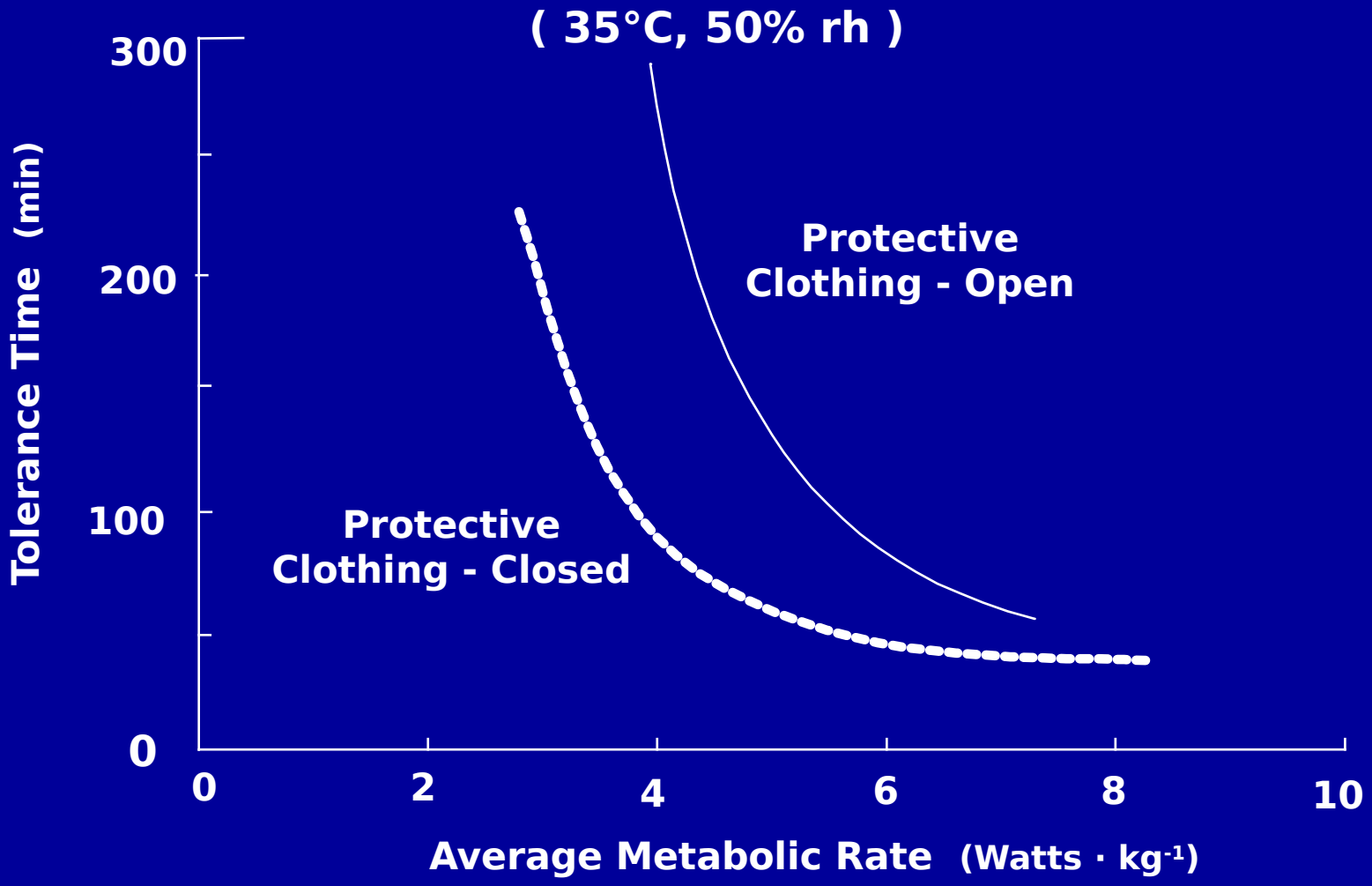
MSMR, 1998

DOA Actions to Reduce Hyponatremia

- **New Fluid Replacement Guidance based on Heat Stress Category & Physical Activity Level**
- **New Upper Limit for Hourly (1 1/2 qts) & Daily (12 qts) Fluid Consumption**
- **New Medical Evacuation Criteria**

Heat Stress Management - *CP Clothing Exercise Rest / Microclimate Cooling*

Relationship Between Tolerance Time & Metabolic Rate While Wearing CP Clothing

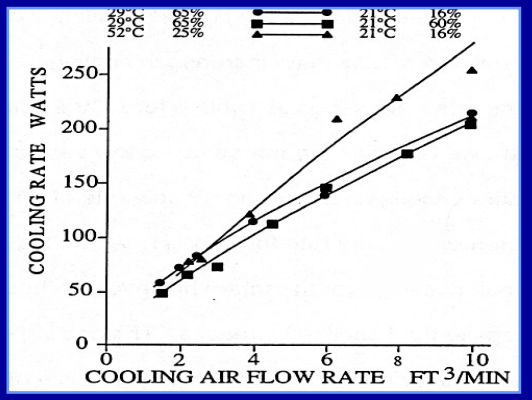


(McLellan et al. ASEM 1993)

Success Story: Microclimate Cooling

Demonstrated Need

Established Cooling Strategies

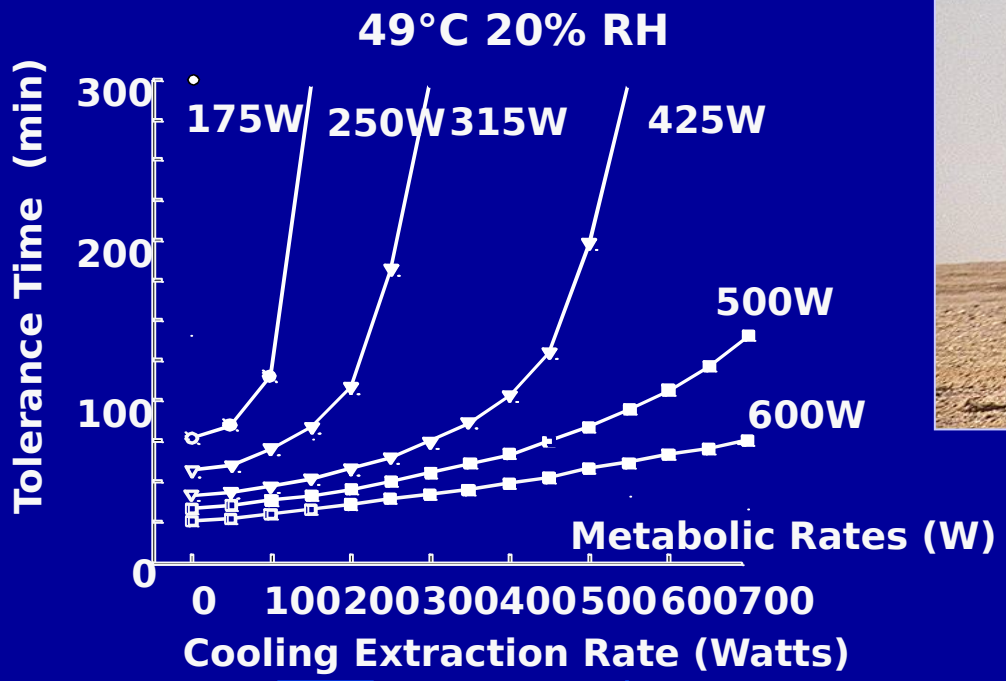


Developed Vests

Tested Systems

Success Story: Microclimate Cooling

Modeled Efficacy → **Gulf War Winner**
M1A1 Abrams Tank



Future War Winner!
Dismounted Soldier
(MCC 300W)

Portable Vapor-Compression Cooling System (PVCS) is a self-contained man-portable NBC micro-climate liquid.

Description:

Refrigeration Unit chills and pumps the coolant through the External Coolant Tether Line, Pass-through, and Internal Coolant Tether Line into the Liquid Cooling Garment.

Specifications:

- Cooling capacity (battery mode): 120 Watt- hours (300 Watts cooling rate)
- 4 hour duration on batteries, indefinitely on 24 volts vehicle power
- Compact size (Refrigeration Unit 416 in^3 , Battery Module 450 in^3)
- Full body cooling through liquid cooling shirt, pants, & hood
- Refrigeration Unit Type: Vapor Compression
- Battery Module: 4 BA 5590 lithium batteries
- Refrigeration Unit Weight: 10lbs.
- Battery Module Weight: 11 lbs.
- Garment weight: 6 lbs.

Personal Ice Cooling System (PICS) is a self-contained man-portable NBC micro-climate liquid cooling system.

Description:

The battery operated mini pump draws chilled water from the NBC sealed Ice Bag and pumps it through the External Coolant Tether Line, Pass-through, and Internal Coolant Tether Line into the Liquid Cooling Garment.

Specifications:

- 150 Watts of metabolic cooling.
- 4 hours duration on batteries, 40 minutes between ice bag change-out
- Battery/Pump Unit (uses 3 D cell batteries)
- Liquid Cooling tubing Under-Garment (shirt with high collar)
- Ice Bag weight: 6.4 lbs.
- Pump / Battery Unit weight: 3.7 lbs.
- Garment weight: 1.5 lbs.

Hot Weather Guidelines

Physical Fitness & Acclimation - Hot Weather

- Maximize Physical Fitness before deployment.
- Fit persons heat acclimatize faster.
- Maintain fitness during deployment.
- Integrate Heat Acclimatization with Training
- Gradually Increase Work in Hot Climates

Reduce Exercise / Heat Exposure

- Reduce exercise intensity.
- Establish mandatory exercise / rest cycle schedules.
  - Tolerance time increased
  - Total exercise increased ?
- Provide shade.
- Avoid hot ground.

Rehydration & Hot Weather Operations

- Thirst is a poor indicator of dehydration.
- Command emphasis on drinking.
- Prehydrate before any work period.
- Resupply at 1h to 3 h intervals.
- Cool & flavor water.
- Plan meals & provide fluids.
- Do not take salt tablets.
- Monitor hydration by color & volume of urine.

Fluid Replacement Guidelines* for Warm Weather Training

(Acclimated Soldier wearing BDU, Hot Weather)

HEAT CATEGORY	WBGT INDEX	WORK					
		EASY		MODERATE		HARD	
	work/rest	work/rest	water	work/rest	water	work/rest	water
	(°F)	(min)	(qt/h)	(min)	(qt/h)	(min)	(qt/h)
1	78-81.9	NL	½	NL	¾	40 / 20	¾
2 (Green)	82-84.9	NL	½	50/10	¾	30 / 30	1
3 (Yellow)	85-87.9	NL	¾	40 / 20	¾	30 / 30	1
4 (Red)	88-89.9	NL	¾	30 / 30	¾	20 / 40	1
5 (Black)	> 90	50/10	1	20 / 40	1	10 / 50	1

Volumes listed are required to support work/rest times listed for each work level. Hourly fluid intake should not exceed 1½ quarts. Daily fluid intake should not exceed 12 quarts.

Key Points: Hot Weather

- Minimize Heat Exposure
- Emphasize Fitness & Heat Acclimation
- Thirst is a poor indicator of dehydration
- Heat acclimatization does not reduce, but increases water requirements
- Water is Not a Magic Bullet
- Weak Link Rule: When the first heat casualty occurs, assess the status of the whole unit